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Related to the Silicate Industries

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Vol. 6

January, 1923

No. 1

A REVIEW OF TWENTY-FIVE YEARS
IN CERAMICS

It was designed that this number of the *Journal* should be a review of the past twenty-five years in ceramics. It was thought this would be a rather easy undertaking with several collaborating, and that two months was ample time and two hundred pages ample space. We believe we need not apologize for the inadequacies of this review. If we have established the fact that a great deal has already been accomplished with very little coördination in effort between the industries and the purely research agencies, and that vastly more would surely be accomplished through a more thorough coördination of all the industrial, technical and scientific agencies, this review will not have been in vain. This coördination of the several agencies in ceramic research and in the industrial application of the results of researches is the program on which the AMERICAN CERAMIC SOCIETY has been collaborating with other organizations with success.

This SOCIETY is entering onto its twenty-sixth year of activities. It will celebrate its twenty-fifth anniversary in a befitting manner during the week of February 12 in Pittsburgh, but its record of activities and growth during the past quarter century are set forth in the following pages.



THE AMERICAN CERAMIC SOCIETY

HISTORICAL STATEMENT OF THE ORIGIN OF THE AMERICAN CERAMIC SOCIETY

By EDWARD ORTON, JR.¹

The circumstances or events which led up to the founding of this SOCIETY, though they are in themselves unimportant and received at the time of their occurrence but little consideration from any one, have been collected and presented in this statement in the belief that if the SOCIETY becomes in future years an adequate representative of the industries for which it stands, its early history will then become of great interest to its membership and it will be difficult or impossible to procure the facts.

At the 12th Annual Convention of the National Brick Manufacturers' Association of the United States of America, held in Pittsburgh, Pennsylvania, on February 15, 16, 17 and 18, 1898, a very excellent paper was read by Mr. Elmer Ellsworth Gorton, of Terra Cotta, Illinois, on the subject of "Experimenting, Wise and Unwise." In this paper Mr. Gorton set forth in illustration of his ideas the results of some of his own experiments in the adaptation of a glaze to a terra-cotta body, writing the chemical formulae of his glazes on the blackboard, and making the necessary calculations to compute the weights of the ingredients needed to make them, before the assemblage. Each experiment was further illustrated by means of trial pieces, showing the result of each modification in composition or treatment which appeared in the text.

This paper was the first of its kind on a chemical topic which had appeared before that Association, and while the novelty of the scientific method of presentation, which Mr. Gorton had adopted, held the interest and attention of the members, it was apparent to all that any extensive addition of this sort to the programs of the Association would be unwelcome, on account of the comparatively small proportion of the members who could understand or follow them.

During the evening of the same day, Mr. Gorton and Mr. Samuel Geijsbeek of New Brighton, Pa., approached the writer and laid before him a scheme which they had jointly prepared subsequent to the reading of Mr. Gorton's paper. This scheme was to form a small Society, which should be a section of the National Brick Manufacturers' Association, or independent of it, as might be thought best, but which should meet at the same time and place as the N. B. M. A., in order to enable the members to maintain their affiliation with that Association. The new Society was to be composed only of Ceramic Chemists or those who would understand ceramic work from the scientific side and would be willing to share their information with their fellow members.

¹ Written in 1899.

This idea matured very rapidly during that day and the 17th of February following. On canvassing the members of the N. B. M. A. present, it was found that only a small number would in any degree fill the technical requirement roughly sketched above, but the following gentlemen were invited by the two original projectors, the writer, and Mr. Albert V. Bleininger, who was early taken into the counsel of the three first named, to meet on the evening of February 18, in the parlors of the Monongahela House and discuss the proposition and if possible form a provisional organization, *viz.*—Messrs. Elmer E. Gorton, Samuel Geijsbeek, Edward Orton, Jr., Albert Victor Bleininger, Willard D. Richardson, Ellis Lovejoy, William D. Gates, Carl Giessen and Gustav J. Holl.

All of the gentlemen invited, reported, and a very enjoyable evening was spent in discussing the plan proposed. No officers were elected except the writer, who was asked to act as provisional secretary. The topics discussed were (1) the qualifications for membership in the Society, (2) the name of the Society, (3) the methods of procedure to bring the desirable elements together for the first meeting. The sense of the meeting in regard to the first topic was expressed in the following sentence written at that time:—

“Membership shall be selected from those who are actively engaged in technical ceramic operations, and who are qualified by education and experience to contribute to the advancement of the Ceramic Arts.” The second topic was discussed at length, but after many suggestions it was thought best to take no action pending the formal organization of the Society. The discussion of the third topic resulted in the adoption of the following plan: That a document, calling for a meeting one year from date, to be held with the meeting of the N. B. M. A., should be at once drawn up and signed by the nine gentlemen present, and, subsequently, an extended statement, setting forth the aims and objects of the proposed Society, should be made by the provisional secretary, and attached to this “Call” as an explanation to those who might be invited to sign the Call, but who had no knowledge of the sentiments actuating the framers of the Call.

The list of persons who should be invited to join in the formation of the proposed Society was then taken up and the following list was agreed upon:—

Karl Langenbeck and Herman Mueller of the Mosaic Tile Company of Zanesville, Ohio; Ernest Mayer, of the Mayer Pottery Company, and F. W. Walker of the Beaver Falls Art Company of Beaver Falls, Pa.; Henry R. Griffin of Phoenixville, Pa., author of “Clay Glazes & Enamels;” Dr. W. H. Zimmer, Chemist of the Wheeling Pottery Company; Edward C. Stover, Assistant General Manager of the Trenton Potteries Company, Trenton, New Jersey; James Pass, Manager of the Onondaga Pottery Company, Syracuse, New York; Prof. H. A. Wheeler, formerly on the

Geological Survey of Missouri, and now Manager of the Standard Tile Company, St. Louis, Mo.; Prof. H. Ries of Columbia University and U. S. Geological Survey; Stanley G. Burt, Chemist of the Rookwood Pottery Company, Cincinnati, Ohio; Charles F. Binns, late of the Royal Worcester Pottery of England, and now with the Ceramic Art Company, Trenton, New Jersey; J. Parker B. Fiske, of Fiske, Holmes & Company, Boston, Mass.; and Dr. Oscar Gerlach of La Salle, Illinois, formerly with the Versuchs Austalt für Keramischer Producten in Berlin.

The document agreed upon as a Call for the meeting was then drawn up and made to read as if already attached to the longer preamble before described, and was signed by the members of the meeting who were present, their names forming the first nine names on the list.

The close of the Convention of the N. B. M. A. occurred the next day, and nothing more was done concerning the new Society till March 1, 1898, when the writer, acting as Secretary, prepared the following preamble to the Call, and began circulating the document among the list of gentlemen agreed upon. The results of this work, which was begun March 11, and was concluded about June 1, 1898, and which was carried on entirely by mail, are shown in the following original document which is here incorporated and made a part of the record.

COLUMBUS, OHIO, March 1, 1898.

At a meeting of the National Brick Manufacturers' Association held at Pittsburgh, Pa., in February, 1898, a small number of members of this Association became imbued with the idea that this Association did not afford a wholly satisfactory means of exchanging ideas on the various branches of ceramic technology, in which they were interested, on the following ground: Papers read at the meeting at Pittsburgh and occasionally in preceding meetings, which touch comparatively lightly on scientific grounds, have, it has appeared, been more complex than the rank and file of the membership of the Association have cared to discuss.

There is a very wide range of subjects which are practically barred for this reason from discussion in the Association's meetings, and yet which seemed to these gentlemen to be of the greatest personal and scientific interest. Accordingly, the idea arose among them that the proper development of their own knowledge and scientific attainments demanded some subdivision of the Association's work. Some discussion was had as to the best means of effecting this end, whether by the formation of a section in the N. B. M. A., or by a completely separate organization, devoted to the kind of work in which they were jointly interested.

I was asked as provisional secretary of this body of gentlemen to draw up this following statement, setting forth the facts, with a view to determining whether it is probable that any such plans as we have in mind

will receive sufficient endorsement by educated clay workers in this country to make them likely to be successful.

It is especially desirable in the outset, to make it clearly understood that we mean no harm, present or future, to the N. B. M. A., to which organization all of the originators of this plan belong and to which they are attached by many ties of friendship and good-will. Our position is not meant to be, nor will it be allowed to become, in any way antagonistic to the older organization, which has done so much towards improving the condition and elevating the status of the common clay industries of the country. But the nature of this organization, and its membership, absolutely preclude its ever becoming in any degree a scientific organization; if it did become such a one, it would at once cease to do the greatest good with the greatest number of its constituents, and would, therefore, soon expire.

We believe that there are at present in the United States quite a number of gentlemen, not affiliated with the N. B. M. A. or any technical scientific organization which gives a proper field for the discussion of the many problems of ceramic technology, who are vitally interested in the discussion of just such things, and who would welcome an opportunity to meet others in an Association where these subjects would receive a full, free and frank discussion for the mutual interest and progress of all concerned. Inasmuch as the ceramic industries of the country so far maintain no organizations other than purely commercial ones, with the single exception of the N. B. M. A., we hope to gather together from all branches of the ceramic industry a number of men who will not only be interested in such a program as has been indicated, but who will also be able both by intellect and education to make substantial contributions to it.

The subjects which we wish to discuss are those connected with the application of science to the practical needs of the clay industry. Naturally, the chemical technology of the clay industry will receive quite a large part of our attention, but the physics of drying and burning, the mechanics of manufacturing, and, in short, all and any branches of technology touching this great industry, will find welcome admission to our program.

The plan as roughly formulated is to have one meeting per year at the same place that the meeting of the N. B. M. A. is held, and either concurrently with it, or just before or afterwards. This time and date was chosen to allow all who wished to attend the meetings of both organizations without much increase of expense. Many of the new Association would still continue active members in the old one, and could not afford to attend separate conventions at different points and times. In addition, it can be said that many members of the new Association would certainly find pleasure and profit from the meetings of the N. B. M. A., and for the opportunities afforded by the machine exhibition rooms and social and

business acquaintances. Also, the hotel and railroad rates of the larger Association would make the expense to members of the small one less onerous.

In the informal discussions which were had at Pittsburgh a small list of names was compiled of persons whom we thought would care to join such an Association or, rather, help to organize such an Association, as we have in mind. This list comprizes, including ourselves, less than thirty names, and it was the sense of all, that this provisional list should be extended with extreme caution, if at all, until after the formal organization takes place.

In our discussions it has been thought best that we should make no constitution or by-laws, or that we should attempt to formulate definitely either a name or a policy, but, in a general way, the points which we have in mind to accomplish are these:—

First: The Association shall receive a name which shall distinguish it as a scientific rather than a commercial organization, and which shall commit it to the investigation of the ceramic industry.

Second: Its membership shall be limited to such men as are not only able but willing to contribute something to the advancement of knowledge along these lines by means of such an organization. The status of its members in the industry commercially, shall not be of importance in determining their attendance to the Association. Their interest in the work and their attainments as ceramic technologists only will be considered.

Third: It is proposed at a meeting to be held in February, 1899, at whatever city the National Brick Manufacturers shall designate for their meeting, to organize the new Association along the lines which have here been roughly sketched out. If a sufficient number sign the accompanying agreement in due season, it is also proposed that the meeting be definitely called and the prospective members be asked to prepare papers, so that our first meeting shall accomplish something besides mere organization.

I am empowered by the originators of this plan to invite you to become one of the charter members of the proposed Association. If you feel disposed to accept this opportunity, I should be glad to have you sign the attached statement.

Yours very truly,
(Signed) Edward Orton, Jr., *Provisional Secretary*.

P. S. The first nine signatures on the accompanying agreement represent the originators of this plan, under whose instructions I am acting in preparing this letter:

“We, the undersigned, hereby state that we are in cordial sympathy with the objects which are set forth in the accompanying circular letter,

relative to the formation of an Association of those who are interested in the ceramic industries in their technical and scientific aspects. We regard this as a much needed step in the direction of progress, for ourselves, individually, and for the ceramic industries of this Country.

"We hereby agree to be present, if possible, at a meeting to be held in February, 1899, at a place to be decided later, there to organize such an Association, and to hold a meeting for the reading and discussion of papers."

S. Geijsbeek, Chemist, Sherwood Bros. & Co., New Brighton, Pa.

E. E. Gorton, Chemist, American Terra Cotta & Ceramic Co., Chicago.

Edward Orton, Jr., Dept. Clay Working & Ceramics, Ohio State University.

Wm. D. Gates, Pres. American Terra Cotta & Ceramic Co., Chicago.

W. D. Richardson, Gen. Manager, Ohio Mining & Mfg. Co., Shawnee, Ohio.

G. J. Holl, Manager of the Ohio Ceramic Engineering Co., Cleveland, Ohio.

Albert V. Bleininger, Appointee to the N. B. M. A. Scholarship, 1897-98.

Ellis Lovejoy, Supt., The Columbus Brick & Terra Cotta Co., Union Furnace, O.

Carl Giessen, Royal Brick Co., Canton, O.

Ernest Mayer, The Mayer Pottery Co., Ltd., Beaver Falls, Pa.

F. W. Walker, Sec. & Supt., Beaver Falls Art Tile Co., Ltd., Beaver Falls, Pa.

H. Ries, U. S. Geological Survey, Columbia University, N. Y. City.

Herman C. Mueller, Supt., The Mosaic Tile Co., Zanesville, O.

Karl Langenbeck, Supt., The Mosaic Tile Co., Zanesville, O.

H. C. Wheeler, Manager, Standard Tile Co., St. Louis, Mo.

W. H. Zimmer, Ph.D., The Wheeling Pottery Co.

Chas. F. Binns, Superintendent of Technical and Art School, Trenton, N. J.

Edward C. Stover, Assistant General Manager, The Trenton Potteries Co.

Stanley G. Burt, Chemist, Rookwood Pottery.

James Pass, Gen. Mgr., Onondaga Pottery Co., Syracuse, N. Y.

Henry R. Griffen, C.E., Phoenixville, Pa.

J. Parker B. Fiske, Boston, Mass.

The completion of the work was announced to the various gentlemen who had thus identified themselves with the proposed Society, by a circular letter, which was prepared on August 6, 1898, and mailed to each member on August 8.

The following is a copy of the letter:—

COLUMBUS, OHIO, Aug. 6, 1898.

Mr. Samuel Geijsbeek,

New Brighton, Pa.

My dear Sir:—

I hand you herewith a list of the signers who have agreed to meet in February, 1899, at a time and place to be designated later, for the purpose of forming an Association of those interested in the technology of the Ceramic Industry. While the above list is not a large one, I think that you will agree with me that it is a very good one and that it comprizes very many of the best known men in this branch of learning in the United States. The need for the Association seems recognized by all who have been approached on the subject and it is my pleasure to announce that every invitation to sign the list has met with a willing response. The meeting place for the coming first meeting cannot yet be announced, but it seems advisable that some arrangement should be set on foot to insure not only the organization of the new Association, but that its first meeting should bring forth some interesting papers and discussions. In fact, with so small a membership, it is likely that the duties of organization and the outlining of our future policy as to extension and the work will occupy a comparatively short time, and the interest and pleasure of the occasion will be greatly heightened if a program other than business can be arranged. Accordingly, I must request each one of you to come prepared with a paper or note or some specific item of interest as his contribution to our first meeting. Furthermore, I will ask that each member notify me as early as possible of the subject which he will discuss, so that a program or announcement can be publicly made before the date of the meeting. There are also other matters which have been suggested as very properly coming before our Association. Among these, the one seeming to awaken most general interest is the matter of securing an American edition of Seger's "Gesammelte Schriften," a book which is destined to become a classic among all clay-workers. The translation of this volume, it would seem, could surely be accomplished without much labor under the auspices of our Association and would undoubtedly prove a further bond of unity between its members.

Congratulating the members on the excellence of the prospect for the Association and urging once more, the importance of immediate work on the part of each, I remain,

Very respectfully,

(Signed) Edward Orton, Jr., *Provisional Secretary.*

The Provisional Secretary received many favorable comments and letters of congratulation and promises of active support in the movement in reply to this letter.

Nothing further was done until December 27, 1898, when the following letter and list of questions was prepared and sent out to the mailing list:—

COLUMBUS, OHIO, Dec. 27, 1898.

My dear Sir:—

Pursuant to a promise, made in a circular letter which I sent you some months ago, I now write to inform you that the meeting of the National Brick Makers' Association will be held in this city, February 7 to 10, 1899. As the scheme of organizing the Association of Ceramic Technologists originated at the last meeting of the National Brick Makers' Association at Pittsburgh in 1898, and as at least one-half of the contemplated membership of the new Association are members also of the National Brick Makers' Association, and would wish to attend the meetings of the latter in any case, and also since our own membership will be so small as to make it difficult to secure the customary reduction in railroad rates given to Associations, it seems best to hold this first meeting of the new Association in Columbus at practically the same time as that of the Brick Makers.

It would also give me great pleasure to have the first meeting of the Association occur in this city and under the auspices of the University and my Department.

The meeting of the new Association ought either to lead or follow that of the Brick Makers. Since the latter will spend Friday of that week in the city, it would seem that it would be better to lead, rather than to attempt to follow their meeting. Their first session will occur at 2 P.M., Tuesday, the 7th, and every day and night until Friday night will be occupied. I would suggest that if our Association could meet for organization at the University, Monday afternoon, February 6, and hold an evening meeting the same day for the reading and discussion of papers, and another meeting on Tuesday morning, the 7th, for the same purpose and for closing up the details of organization and the adoption of the Constitution, etc., we would find in these three sessions time enough for the successful completion of all of the work of this first meeting. In case it should transpire that a little more time was desirable, I think without doubt the members of the Brick Makers' Association could excuse themselves from one of the sessions of the latter Association.

In order to decide this matter definitely, I will therefore ask each member to fill out the enclosed blank and mail it to me at the earliest possible date. I would also urge on each of you the desirability of having some paper, or subject for discussion, or note, to present before the Association at its first meeting. Our power to do ourselves and each other good, and

the future strength and influence of the organization on the Ceramic Industry of the country will depend very much on the way that this first meeting passes off. I earnestly hope that it will be a thoroughly successful meeting from the standpoint of the technical papers presented, and the discussions evoked, and that the whole spirit of the meeting will be one of enthusiastic work on the part of each member. To realize such an end, each one of us must be a contributor, be it ever so little, to the results of the meeting. For this reason, I beg you will fill out the enclosed blank in full.

Awaiting your reply, I remain,

Yours respectfully,

(Signed) Edward Orton, Jr., *Provisional Secretary*.

Questions

I—Will the date Monday, February 6, 2 P.M., to Tuesday, February 7, 12 M., suit you for the date of the first meeting?

II—If not, would a meeting February 11 and 12 suit you better?

III—Will you be present at the meeting so far as you can foresee?

IV—Please indicate here the final title of your paper as you wish it to appear on the program.

V—Please indicate here the subject of a short note, talk or informal discussion in which you will agree to take part.

VI—Please indicate here the subject of any question which you would care to have discussed, but in which you do not feel able to participate.

Please note that prompt replies will be necessary in order to permit the preparation and mailing of a suitable program.

Replies to this were received from twenty out of the twenty-two members of the list, and the indications for a literary program appeared so excellent that a formal announcement was prepared and sent out on February 1, 1899.

The first meeting of the SOCIETY occurred as set forth in the above circular and from that point forward its minutes tell its history with all the accuracy necessary.

This sketch is inserted at the head of the records of the AMERICAN CERAMIC SOCIETY, according to a resolution passed at the second meeting, July 4, 1899, and found in the minutes of that meeting.

TWENTY-FIVE YEARS OF THE AMERICAN CERAMIC SOCIETY

BY NORAH W. BINNS

Early Meetings

In accordance with the summons outlined in the foregoing statement, fifteen "signers of the Call" duly gathered at Columbus, Ohio, on February 6, 1899. The group was fully aware of the value of strong leadership

in the undertaking and promptly elected Edward Orton, Jr., Secretary of the SOCIETY, a position he held for nearly twenty years and the duties of which he executed with inspired faithfulness. H. A. Wheeler, of St. Louis, was elected first President, and S. G. Burt, of Cincinnati, was called upon to fill the office of Treasurer, to which he was reelected at eight annual meetings.

A review of this meeting shows four characteristic actions of the SOCIETY, auguries of the attitude to be taken on certain large questions for the coming twenty-five years. That this is so, is cause for admiration and respect for the breadth and clearness of vision of the founders and charter members of the SOCIETY.

As a preparatory step a Constitution had been carefully drawn up prior to the meeting, and it is noteworthy that the SOCIETY operated under the rules then adopted without amendment until 1911. This small body of men showed themselves able to prepare a set of rules fitted to govern them unchanged for ten years and with certain modifications for twenty-five.

A second important and typical action was the proposal to translate into English the writings of Hermann A. Seger, pioneer scientific ceramist of the world. Thus the SOCIETY showed at once its desire and purpose to render real service to the industry at personal sacrifice and for no selfish end.

A third matter which was presented at the first meeting shows a keen interest in the attitude of the United States Government toward mines and mining, akin of course to ceramics, and a readiness to shoulder responsibility and to demand action from others.

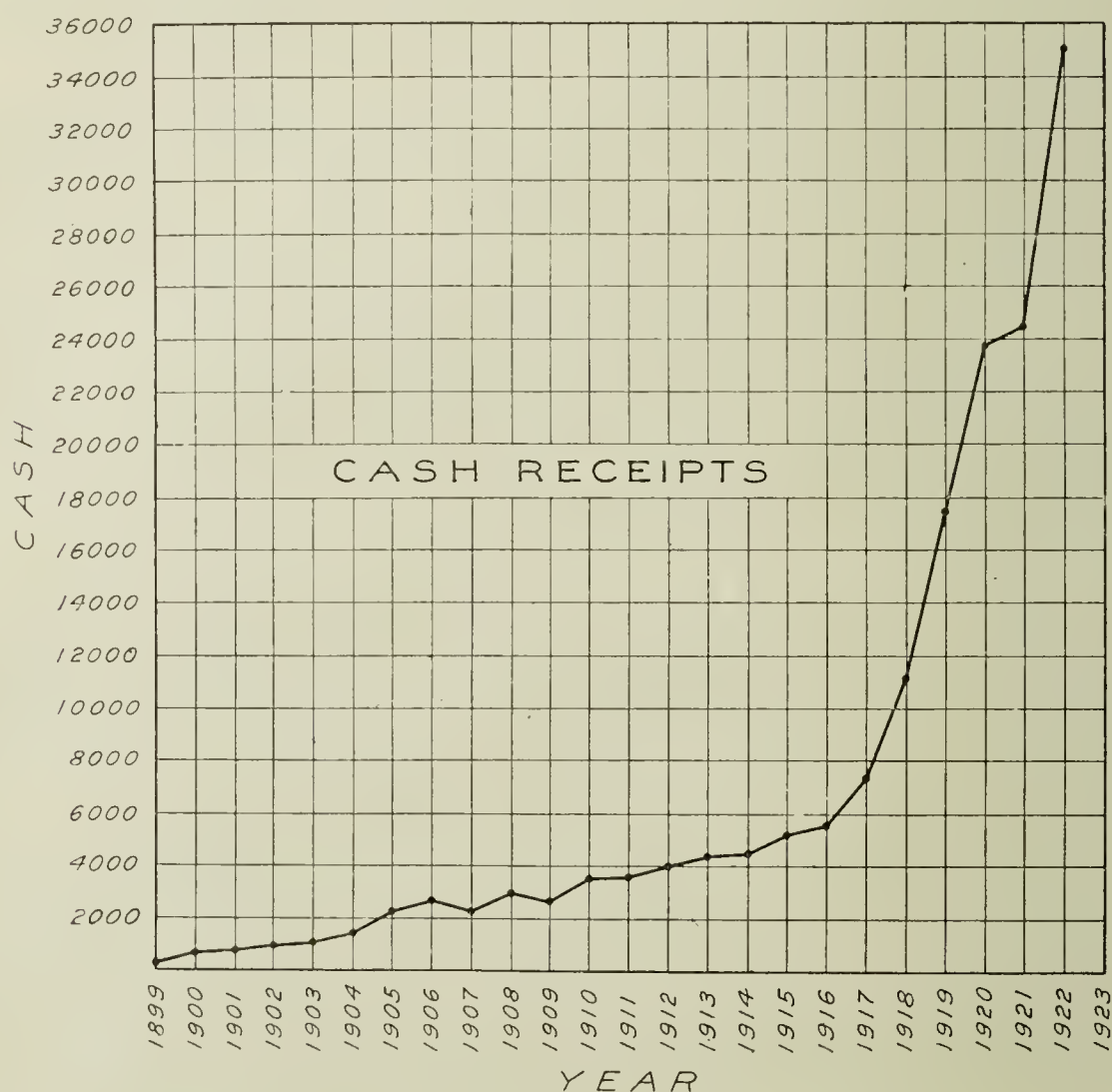
The fourth side exhibited at that memorable meeting was the educational. Certain papers which were presented provoked plans for concerted action by the members. Committees were appointed to consider the testing of clays, and to make recommendations for the establishment of standard ceramic equivalent weights.

The SOCIETY thus put itself on record at its first meeting as a well-ordered body with definite rules and regulations, as a sponsor for scientific contributions to ceramic lore from other countries, as an advocate for government support of ceramic problems, and as a reasoning group proposing to put into execution the conclusions of its members.

With this beginning, annual meetings were held without interruption, the attendance growing, sometimes by twos and threes, sometimes by scores, but always growing. Summer excursion meetings were held with a few exceptions in the early years, when the Pan-American Exposition or the World's Fair proved too diverting. Since 1909 there has been no lapse in the summer meetings.

At the smaller meetings of the early years naturally the personal point of view was retained and emphasized. The elevation of associates to ac-

tive membership was always an occasion of dignity and solemnity. The President of the SOCIETY invariably invited the newly elected active members to the platform where he greeted them with words of congratulation and advice and hearty handclasps. The qualifications of an active member were brought out in many a presidential speech, first, that technical ability was required, and, second, that technical ability must be supplemented by a desire to impart his stores of knowledge and to serve his neighbor and mankind. The innate spirit of the charter members was thus inculcated in the recruits, who were able in their turn to lead.



Intimacy naturally marked the relations between these men who were drawn together by no slight bond. As much concern was felt for one another in time of illness, accident, or misfortune, as if they were members of the same family, and one cannot remain unmoved on reading the account of the solemn occasion of the announcement of the death of a charter member.

Another element which can never be found among the great numbers at our modern meetings is the spirit of Section Q. Ask any member of the first five years what he enjoyed most and he will say, "Section Q." The need for recreation was not satisfied by dancing and moving pictures. It was talk and more talk that these men craved. Formal papers were given morning and afternoon but in the evening, in a private room or

around a table, refreshments of the good old variety were made available, cigars and pipes were lit, and Section Q was on. Many of the members were working alone, so far as scientific sympathy or understanding was concerned. All of them had problems, all of them had a little knowledge. Put together, the bits of knowledge gradually began to penetrate the problems. Section Q was the earliest form of ceramic "coöperative research."

A portly professor at one Section Q was heard to say that he intended to catch the ten o'clock train for home. Shortly afterwards came the remark, "Why, it's ten-thirty now. Well, I'll take the midnight train." A few more experiences were exchanged and he cried, "Heavens, it's a quarter of one. I'll have to take the two o'clock." The historian does not know whether he actually made this train or not.

These staid professors and sober business men were like schoolboys when they met each other. On one occasion a charter member had to make a speech at the banquet of another organization, meeting at the same place. He stayed at his beloved Section Q as long as he could, then rushed away to keep his engagement. A loyal friend proposed that their group should support the speaker by going in a body to hear him, and so they did. But before their companion's speech they had to listen to an interminably long address by someone else. Worn out but at last able to get away they looked for the man who had suggested coming to the banquet, only to find that he had retired long since and was soundly sleeping. To make the punishment fit the crime, an urgent call for five A. M. was left at the clerk's desk for the sleepy one.

It is amusing to note the hotel rates which prevailed at the earliest meetings. All expenses for four days were estimated at ten dollars at one meeting. On the American plan, which was customary then, the hotels charged three dollars a day. The bill for the expenses of his office for the first year was deprecatingly presented by the Secretary since it amounted to more than he had anticipated. The total was twenty dollars and fifty cents. What the growth of the cash receipts of the SOCIETY has been is shown on the accompanying chart.

Seeger's Collected Writings

As has been said, the translation of Seeger's *Writings* was proposed at the first meeting. Several members who were conversant with German had offered to do parts of this work and it was promptly taken in hand, A. V. Bleining serving as Editor. The size of the two volumes which were finally published is well known, and it will readily be seen that hard work was necessary to have the first volume ready for distribution at the fourth annual meeting of the SOCIETY, while the second was ready at the time of the fifth summer meeting. All of the work of translation was done by

members of the SOCIETY with no remuneration whatever. A subscription list was circulated and more than enough sales were made to satisfy the requirements of the publishers. The work is still considered authoritative and its comprehensiveness recommends it to students of all branches of ceramics.

Manual of Ceramic Calculations

Another important publication which was initiated at the first meeting was the *Manual of Ceramic Calculations*, as the report of the Committee on a Scale of Ceramic Equivalent Weights was afterwards called. This Committee did its work between the time of the first annual meeting and the second summer meeting, and its findings were reported in Volume II of the *Transactions*, the *Manual* being issued later as a reprint. This was in demand as a textbook for many years and requests for it are still received, although it is now out of print.

Incorporation

In 1905 it was found necessary for business procedure in the state of Ohio to incorporate the SOCIETY. Nine members, residents of Ohio, under the leadership of Professor Orton, signed the articles of incorporation, and all members were made parties thereof, by virtue of the signatures on their applications.

Ceramic Schools

From the first the SOCIETY staunchly supported the establishment and maintenance of ceramic schools. Ohio State's Ceramic Department preceded the founding of the SOCIETY by five years, while the New York State School of Ceramics followed it one year later. At its fourth meeting, the SOCIETY voted to send resolutions to the New Jersey legislature, urging the establishment of a department of ceramics at Rutgers College, evidently to some purpose, for at the fifth meeting a paper describing the new department was given. After the World's Fair at St. Louis in 1904, where the SOCIETY exhibited a set of its *Transactions* and was awarded a silver medal by the judges of technical literature, the books were donated as a nucleus for the library of this school. In 1907 resolutions were again sent to the New Jersey legislature endorsing ceramic education in general, setting forth the good that had been accomplished and urging increased appropriation for Rutgers.

Similar support was given from time to time to Illinois and the other ceramic departments as they came before the state legislatures.

Bibliography of Ceramic Arts

In 1906 Dr. J. C. Branner, of Stanford University, offered to the SOCIETY for publication a bibliography of ceramic arts, upon which he had

been working for some time. This offer was accepted with appreciation of its generosity, and Dr. Branner was made an honorary member of the SOCIETY. The volume was issued the same year.

Committee Work

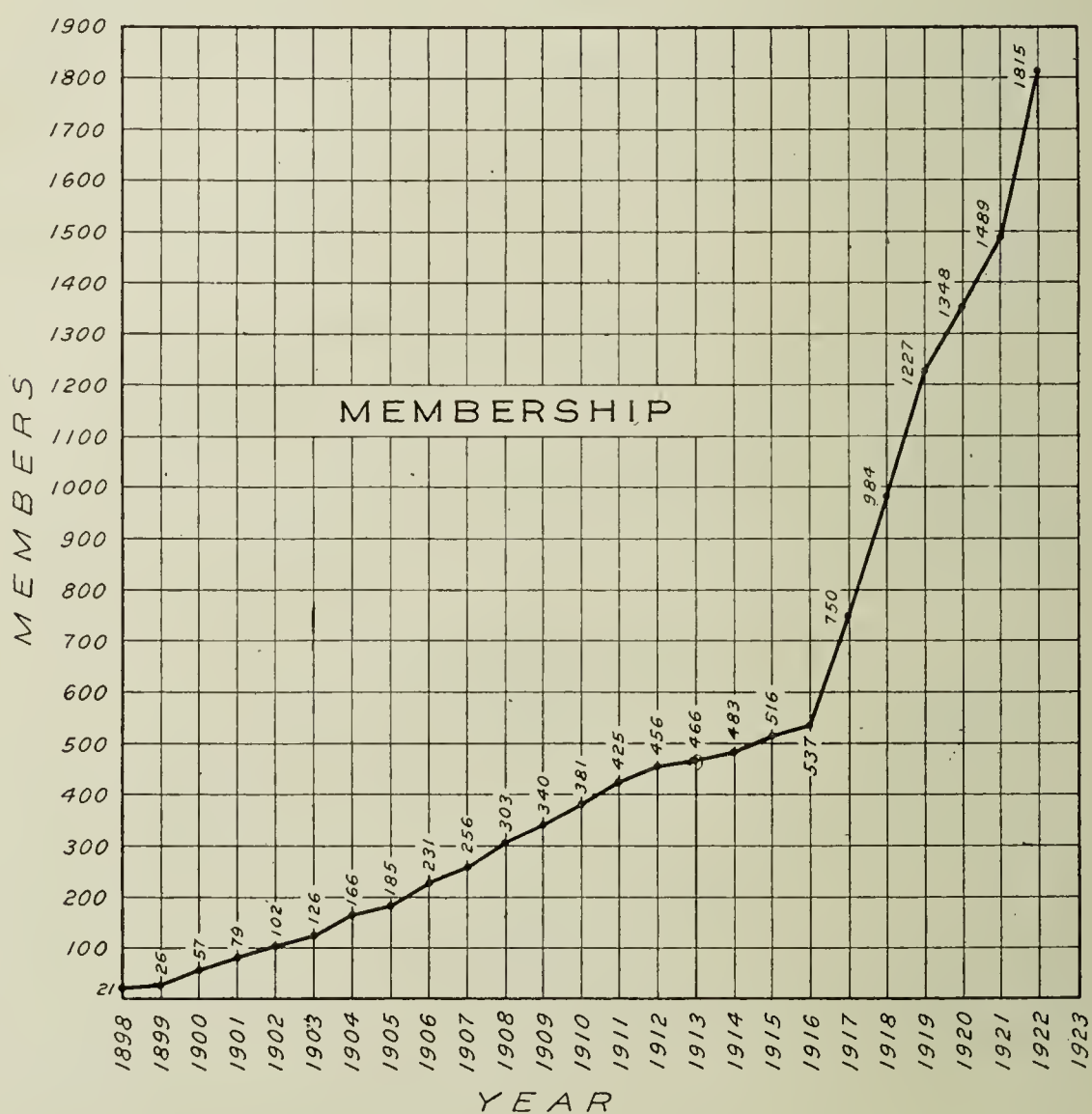
Committees have always been integral parts of the SOCIETY. Sometimes conspicuous success followed their work, as has been described; sometimes, through lack of time or other reason, results were not seen for years.

A most important achievement was that of the Committee on Co-operation with Federal and State Geological Surveys. The appointment of this committee was prompted by the reading of a paper by Mr. R. R. Hice, State Geologist of Pennsylvania, at the 1906 annual meeting. The committee, of which Mr. Hice was made chairman, was not appointed until January, 1907, but began to work at once and at the next meeting a vigorous discussion took place, with contributions by Mr. H. Foster Bain, then Director of the State Geological Survey of Illinois, and Dr. E. R. Buckley, State Geologist of Missouri, in addition to the members of the SOCIETY who were in close touch with the work of the Surveys. The purpose of the Committee, then outlined, was to bring the influence of the AMERICAN CERAMIC SOCIETY upon the U. S. Geological Survey in the organization and operation of a clay-testing laboratory, and to confer with all the Surveys who were investigating clays, in the points to be covered by a geological report which should be of real service to ceramists.

The comprehensive report, written by Mr. R. C. Purdy, secretary of the Committee and ceramist of the Illinois Geological Survey, and printed in Volume IX of the *Transactions*, shows that in May, 1907, documents were spread before the U. S. Geological Survey, urging the creation of a laboratory for research in the testing of clays and clay products, to develop a system whereby other groups would be enabled to carry on practical applications and tests, and demanding the appointment of a scientific and technically trained ceramist to take charge of such a laboratory. Furthermore, the Committee outlined a method of attacking the problems, and the points to be covered, emphasizing that the investigations of the laboratory should be scientific rather than industrial. To the State Surveys, the Committee made recommendations that problems of a stratigraphic, areal, local economic or industrial nature should be investigated.

The results of this work are well known. A Structural Materials laboratory was established in the Technologic Branch of the U. S. Geological Survey and Mr. Bleininger was made director, with two other members of the SOCIETY on his staff. In 1909 a threatened curtailment of the appropriation for this branch put the AMERICAN CERAMIC SOCIETY on its mettle and a veritable flood of telegrams and letters to congress-

men effectually drowned out the voices of the over-economical, and the amount was made higher than before. Efforts were still put forth for the establishment of a federal bureau of mines and mining, and in 1910 the proposal met with favor and the bill was passed. At the same time the structural materials investigation was turned over to the Bureau of Standards, who retained the technical staff and continued the work. For some time the Bureau of Standards was the only federal body touching ceramics, but of late years both the Bureau of Mines and the Geophysical Laboratory have been initiating new work.



A step was taken toward a Committee on Standards at the first meeting of the SOCIETY but there were various lapses of appointment and no tangible work was accomplished for some years. In 1917 this Committee worked out tentative methods of clay testing, which were reported at the annual meeting in 1918. Two years of labor followed, revising and perfecting the tests, and six methods were finally adopted by the SOCIETY as standard in 1920. A sub-committee of the Committee on Standards in 1918 issued a *Directory of Dealers in Raw Ceramic Materials* which filled a need.

Committees on Ceramic Education, Nomenclature, War Service, etc., were appointed from time to time and did valuable work.

Four members, appointed by Board of Trustees to serve as Chairmen of Committees 1 to 4, inclusive

		Committee members	Coöperation with other organizations
1. Committee on Research	Pure Science Applied and Industrial Science	3 members appointed by Board 1 member chosen by each Division	National Research Council (Div. Chemistry and Chemical Technology, Div. Research Extension, and Div. Engineering) Federal Bureaus Semi-Public, Commercial, and Industrial Laboratories Universities Trade and Technical Associations
2. Committee on Standards	(a) Definitions (b) Raw Materials Specifications (c) Standardization of Tests (d) Standardization of Products	(a) 3 members appointed by Board (b) 3 members appointed by Board (c) 1 member chosen by each Division (d) 1 member chosen by each Division	American Society for Testing Materials (Committees C-1 to C-11, inclusive, D-4, and D-9) Foreign Ceramic Societies Trade and Technical Associations Federal Bureaus American Engineering Standards Committee, etc.
3. Committee on Geological Surveys	Advisory on Tests and Interpretation of Data	4 members appointed by Board	National Research Council (Div. Geology and Geography) U. S. and State Geological Surveys
4. Committee on Data	(a) Symposiums (b) Monographs (c) Bibliographies (d) Statistics	1 member chosen by each Division	National Research Council Trade and Technical Associations Federal Bureaus Commercial Laboratories Universities

Up to about 1909, as was right, new members were only those who asked for admission, but now there was evident need for increased strength in numbers and finances, and the first indication of the modern campaign can be seen in the slogan sent out by the dignified Secretary, "Land a new member and sell him a set of the *Transactions*," and the Membership Committee began to do active work. The results are shown in the diagram of the growth of membership by years.

At a conference in September, 1921, the plan of a Coördinated Service Council was endorsed, whereby the Committees on Research, Standards, Geological Surveys, and Data were grouped as service committees, their chairmen forming the Service Council. The duties, personnel, and proposed contacts of each committee were carefully worked out at this time and are outlined in the chart preceding.

To this has since been added a Committee on Ceramic Education whose duty it shall be to foster the existing departments of ceramics, to stimulate the founding of others, and to promote the technical education of the practical worker in the industry.

Corporation Members

It is interesting to trace the development of Corporation Membership in the SOCIETY. In 1903 a request for admission to membership was received from a firm and after careful conclave it was courteously but firmly refused. Whether this rankled in someone's thrifty soul we do not know, but in 1908 it was proposed to have a class known as Contributing Members, to which firms should be invited to belong. This was the first amendment to the rules drawn up in 1899. Because the proper end of the ball of red tape could not at first be found, action was delayed for two years. When the amendment was finally incorporated no active soliciting was begun because of the business depression of that time. The following year the need for additional funds seemed to be less acute and again no effort was made. The evident reluctance on the part of the officers to invite firms to become Contributing Members was doubtless based on the feeling that since firms as such could not attend the meetings the good to be derived would be slight and the dues paid would be so much charity. However, in 1912, five firms were listed as Contributing Members, one of whom has persisted for ten years without a lapse. The matter did not receive special attention for several more years, but in 1918 the term used was changed to Corporation Members, active solicitation was begun, and 1922 saw more than two hundred in this group.

Local Sections

Before the SOCIETY had conceived the idea of broad-casting itself, a group of ceramists at Beaver Falls, Pennsylvania, had organized the Beaver

Ceramic Society and was holding enthusiastic meetings. The New Jersey Clay Workers' Association was similarly organized and was doing united work. It was proposed in 1915 to establish local sections of the AMERICAN CERAMIC SOCIETY in different parts of the country for more frequent meetings than were possible by the national body, and to encourage especially the membership of the practical man. The group in the Beaver locality was the first to re-organize and was installed as the Beaver Section of the AMERICAN CERAMIC SOCIETY in August, 1915. Later the name was changed to the Pittsburgh District Section, in order to include a larger territory.

Other local sections followed suit and charters were applied for by Northern Ohio, Central Ohio, New England, New York State, Chicago, and St. Louis in 1918, while a year later the New Jersey Association became the Eastern Section of the AMERICAN CERAMIC SOCIETY. From time to time tentative proposals have been made for the formation of sections in the far west and in other centers.

Quarterly meetings have been held by most of the sections and they have been instrumental in producing papers for the annual meetings, in obtaining new members, and in securing expressions of public opinion on proposed changes of policy.

Student Branches

The same year that the Beaver Local Section of the SOCIETY was installed the Ohio State University Ceramic Department asked that their student society be given some status in the national SOCIETY, and Student Branches were instituted. At Ohio the branch was grafted in the spring of 1915 and the New York State School of Ceramics, at Alfred, was duly added in October. The other schools, Illinois, Rutgers, and Iowa, were not far behind, and all have flourished.

Industrial Divisions

Long before the Industrial Divisions as we know them were thought of, it was found necessary to divide the meetings into two groups, in order to cover the number of papers offered and to provide some choice for the interests which were gradually becoming diverse rather than unified. In 1909 two groups met under the chairmanship of the president and vice-president, respectively, one to discuss white ware problems, the other, heavy clay products. Nothing more definite was done until 1914 when a plan was produced calling for "permanent committees" or "topical sections," which were to be responsible for the securing of papers and discussions, to arouse the interest of others in each phase of the industry, and to arrange for a definite part of the scheduled annual program. The

“committees” suggested were six, namely, Pottery, Glass, Enameled Iron, Refractories, Structural Materials, and Cement and Lime. It is noteworthy that the divisions as fully organized in 1921 comprised practically this list with the addition of Terra Cotta and Art.

Probably delayed by the War, it was not until 1918 that the Board of Trustees took action on the method of procedure for the formation of “industrial divisions” as they were by that time known. The Enamel, Glass, Refractories, and Terra Cotta divisions were promptly established and have pursued uninterrupted programs of progress. The Heavy Clay Products and White Wares Divisions followed more slowly but began to function in 1921, while the newest addition, the Art Division, began to make itself felt in 1922. In August, 1919, the Board voted to allot 10% of the dues of the members of a division to that division for its operating expenses; the Committee on Rules drew up a model set of by-laws for the guidance of the divisions, and in every way their efforts have been encouraged. The achievements of each division cannot be enumerated here, but there is no shadow of doubt that their organization was one of the biggest bits of work ever done by the SOCIETY.

Publications

Transactions.—At the tenth annual meeting of the SOCIETY, which was of course the occasion of special celebration, the President produced, side by side, Volume I and Volume IX of the annual *Transactions*. The comparison would be ludicrous but for the fire of the pioneer blazing between the covers of the tiny book known as Volume I. This cannot be quenched by any streams of knowledge and investigation published later, and it is chiefly for this that the earlier volumes are honored. The nineteen volumes of *Transactions*, published from 1899 to 1917, form an impressive ceramic library. With the translated works of Seger, mentioned before, and the *Transactions of the English Ceramic Society* founded in 1906, they constitute practically the only technical literature on ceramics published in English during that period. Their value, historically and technically, is immeasurable.

Index.—The *Index to the Transactions* compiled under the direction of the Committee on Publications and issued in 1920 makes the set of volumes a reference work of easy access.

The Journal.—The present *Journal of the American Ceramic Society* can trace its inception back to 1905 when it was voted to publish the *Transactions* in quarterly installments. This venture was attended with indifferent success, and in 1906 a return was made to the single annual volume. The idea never quite died out, however, and in 1917 a Committee was appointed to investigate the possibilities of issuing a quarterly

or a monthly. At the meeting of 1918 it was voted to begin at once to publish a monthly journal, and Professor G. H. Brown, of Rutgers College, was made Editor. The struggle with time that the editors had is too fresh a story to need repetition, and it was not until 1922 that actual scheduled publication date was reached and adhered to. Professor Brown edited the *Journal* for two years, but was obliged to resign on account of pressure of other work. Mr. H. F. Staley, of the Bureau of Standards, succeeded him and was Editor for 1920. His resignation led to the appointment of Dr. E. W. Washburn, of the University of Illinois, who piloted the periodical through 1921, and who in turn was succeeded by Mr. R. C. Purdy, when the latter became General Secretary and Editor in 1922.

The increase in membership necessitated an annual increase in the number of copies printed in order to keep the reserve stock uniform. In 1921 the annual subscription rate was raised from six to eight dollars on account of the increased cost of printing.

The number and character of the "original" papers printed have improved steadily. In 1899, eight papers were published in Volume I, and the range of subjects was simple; in 1908 there were thirty-four papers on a diversity of subjects; while in 1922 there were one hundred and five papers published. A subject analysis of the original papers published in the first five volumes of the *Journal* shows the following figures:

TABLE I

	Vol.	1	2	3	4	5
Art.....	1	0	3	3	9	
Geology of Ceramic Materials.....	5	6	1	0	4	
Chemical, Physical, and Physcio-Chemical....	10	13	8	13	13	
Enamels for Metals.....	7	4	5	8	6	
Equipment for enameling and factory practice.....	0	0	1	2	7	
Glass and Glass Products.....	8	5	8	4	4	
Glass house equipment and management.	2	5	7	7	5	
Heavy Clay Products.....	1	0	2	2	6	
Kilns and dryers.....	7	11	8	6	7	
Lime, Plaster and Cements.....	4	2	3	3	2	
Refractories, General.....	0	1	2	6	7	
Clay.....	0	2	1	0	0	
Silica.....	2	0	0	4	4	
Magnesite.....	2	1	2	1	0	
Chrome.....	0	0	0	0	2	
Graphite.....	0	5	1	1	0	
Special.....	1	0	2	1	1	
Terra Cotta, Materials and Methods.....	3	0	5	4	7	
Equipment.....	1	0	0	1	2	
White Wares, Saggars.....	1	1	2	3	0	
Bodies.....	4	9	5	4	6	
Glazes.....	1	1	4	3	3	
Methods and processes.....	1	2	1	0	5	

Ceramic Abstracts.—Though the first number of *Ceramic Abstracts* appears in the May, 1919, number of the *Journal of the American Ceramic Society*, this too had received attention as early as 1905. A Committee on Ceramic Literature was then formed, which for a short time made notes and reviews of foreign papers on ceramic subjects. Because the work was necessarily intermittent and was being done in part by *Chemical Abstracts*, this committee was discharged and the matter was held in abeyance until the publication of the *Journal* made an abstract service possible and *Ceramic Abstracts* as a part of each number of the *Journal* was begun as soon as feasible. In the first number to contain these there were sixteen abstracts, while in December, 1922, there were one hundred and ninety-one, a mushroom-like growth, which nevertheless has stability.

The Bulletin.—There has always been more or less rivalry between the practical man and the scientific man, between whom now stands the so-called technical man. In 1909, the President of the SOCIETY made a plea for more practical papers, for as knowledge and education increased the tendency was to prepare papers of an abstruse nature, of prime interest to the student and research worker. In 1922, an effort was made to fill both sides of the scale and keep them in balance. Accordingly, the *Bulletin of the American Ceramic Society* was begun, first as a separate publication and then under the same cover with the *Journal*. This, so far as can be told in one year, has proved satisfactory, since it provides an outlet for material of less permanent value than the papers in the *Journal* but just as interesting, particularly to the practical and the technical men.

Full-time Secretary

The latest step to be taken in the development of the SOCIETY has been the appointment of a full-time Secretary. This was a question which popped up almost annually from 1908. Professor Orton for many years handled not only the Secretary's office but the editorship of the *Transactions*, single-handed and unremunerated. He frequently urged the creation of the office of paid editor, who, when expedient, should become secretary also.

It was found necessary in 1909 to begin to pay the person who edited the *Transactions*, though the amount was never commensurate with the effort.

Upon Professor Orton's resignation from the secretaryship in 1917, when he entered the army, Professor Binns, of Alfred, himself a charter member of the SOCIETY, first and only director of the New York School of Ceramics, was asked to take over the work. There was a tacit understanding at this time that it would not be long before the employment of a full-time secretary would be possible and desirable, and in 1921 a committee appointed for the purpose recommended to the Board of Trustees

that the step should then be taken. Endorsed by many of the local sections and by scores of individuals, Mr. R. C. Purdy, of Columbus, Ohio, was appointed Organizing Secretary in July, 1921, to become General Secretary in January, 1922. Permanent headquarters for the SOCIETY were then established at Lord Hall, by courtesy of the Ohio State University.

At the annual meeting in 1922, Mr. Purdy was asked to take the editorship of the *Journal*, *Abstracts*, and *Bulletin*, since it was deemed desirable to have the two offices in one for the time being.

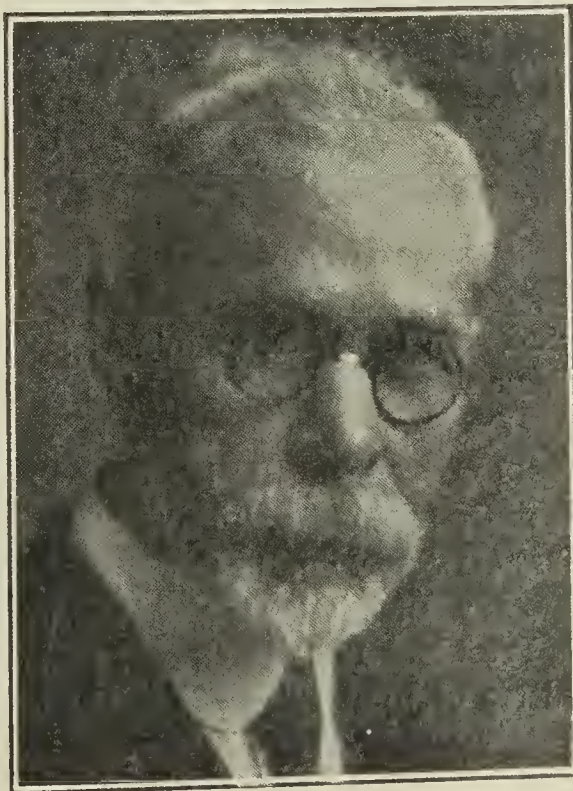
Conclusion

The task of compiling the history of the AMERICAN CERAMIC SOCIETY has been an interesting one. These twenty-five years have seen the SOCIETY pass through the period of infancy when loving hands tended it with solicitude, through adolescence, the time of physical growth and keen enthusiasms, to manhood. When the SOCIETY "came of age" four years ago, there seemed to be a buckling on of armor for sturdier crusading than ever before. There was a determination to render service, to pull together previously conflicting or overlapping interests, and to show real leadership. Since its twenty-first birthday the SOCIETY has redoubled its efforts for efficiency and coöperation, and although it cannot be said that the aim has been reached, else the limit had not been nearly high enough, yet certain sure strides have been taken and the goal is nearer and clearer.

CHARTER MEMBERS

Charles Fergus Binns

Charles F. Binns, director of the New York State School of Clay Working and Ceramics at Alfred, New York, since its founding, was born in Worcester, England, in 1857. Mr. Binns entered the Cathedral King's School in his native city and began the usual classical education of an English boy. At the early age of fourteen he was withdrawn from school and was taken as an apprentice at the Royal Worcester Porcelain Works. At that time chemistry was not taught in the city, so arrangements were made for him to visit the neighboring city of Birmingham in order to study this subject. Following upon this a laboratory was equipped at the manufactory and some attempt was made at chemical control of operations. For a number of years Prof. Binns resided in London in charge of the city sales agency and at this time lectured before the Society of Arts and other organizations. In 1897 Professor Binns came to the United States and located at the newly-formed School of Applied Art in Trenton, New Jersey. For two years he worked in the laboratory of the School by day and taught at the Art School



CHAS. F. BINNS

in the evening. In 1900 when the New York State School of Ceramics was to be established, the President of Alfred University and Mr. Charles T. Harris visited Trenton and an interview took place which resulted in the appointment of Mr. Binns to the directorate of the school. In recognition of his work Alfred University gave him the honorary degree of Master of Science in 1901.

The call issued in 1898 for the formation of the AMERICAN CERAMIC SOCIETY found a ready response in Mr. Binns and he became a charter member of the SOCIETY. At the first meeting in 1899 he was elected Trustee, the following year he was made Vice-President and in 1901 he was chosen President. In 1918, when Professor Orton's resignation necessitated the choice of a new Secretary for the SOCIETY, Professor Binns was asked to take the position which he filled for four years. Prof. Binns is a member of the English Ceramic Society and of various art organizations and is a Master Craftsman in the Boston Society of Arts and Crafts. He is the author of numerous papers which have appeared in the *Transactions* and the *Journal of the American Ceramic Society* and in other publications and also of two books on the potter and his craft.

Albert V. Bleininger

Albert V. Bleininger was born in Polling, Bavaria, in 1873. From 1889 to 1896 he worked in the clay industry receiving shop experience and in 1897 he completed a short course in Ceramics at Ohio State University. His Bachelor of Science degree



A. V. BLEININGER

in chemistry was received from this Institution in 1901. For four years, from 1898 to 1901, Mr. Bleininger acted as laboratory assistant in ceramics and until 1907 was instructor, assistant and associate professor at Ohio State University. He served as assistant to the Ohio Geological Survey from 1900 to 1904.

In 1907 Mr. Bleininger went to the University of Illinois where he was assistant professor in Ceramics. During the years 1908 to 1910 he was in charge of the clay products section of the United States Geological Survey. In 1910 he returned to the ceramics department of the University of Illinois as professor and director of the department. This position he retained until 1912 when he accepted an appointment by the Bureau of Standards as section and division

chief. In 1920 Mr. Bleininger left the Bureau of Standards to become chemist for the Homer-Laughlin China Co., in Newell, West Virginia.

One of the most valuable contributions made by Mr. Bleininger to the ceramics world was his translation of the complete writings of Seger. He has also contributed liberally to the literature of ceramics with writings for the *Transactions of the American Ceramic Society* and other technical journals.

Mr. Bleininger is a charter member of the AMERICAN CERAMIC SOCIETY and acted as President 1908-1909. At present he is serving as Chairman of the Technical Committee of Joint Research of the four heavy clay products associations.

Stanley G. Burt

Stanley G. Burt was born in Cincinnati, Ohio, in 1870. He was graduated from Yale University in 1892, and one month later went to work at the Rookwood Pottery

Company of Cincinnati. In 1894, he was absent for one year while he studied the chemistry of pottery in Berlin. Returning the next year to Rookwood, he took charge of the Chemical Department, and in 1898 became Superintendent of the Company.

Mr. Burt served as Treasurer of the AMERICAN CERAMIC SOCIETY from its organization in 1899 until 1905-1906, and during 1907-1908 was President of the SOCIETY.



STANLEY G. BURT

J. Parker B. Fiske

J. Parker B. Fiske, President, Domestic Oil Heating Co., Boston, Mass., was born October 8, 1865, at Medfield, Mass. He studied mechanical and electrical engineering at the Massachusetts Institute of Technology of Boston, graduating therefrom with the degree of S.B.

His first position was with the Thompson-Houston Electrical Company, of Lynn, Mass., from 1889 until 1896, when he went into partnership with his father at Boston, Mass., in Fiske & Co., Inc., manufacturers of burned clay products. In 1918 he went with the Marlin-Rockwell Corporation as General Manager of its Standard Roller Bearing Department at Philadelphia. Later he accepted the position of President and General Manager of the Sunnyhome Electric Company of Detroit, Mich. (a Division of the General Motors Corporation), manufacturers of farm lighting and power plants, and in July, 1919, he had added to these duties the Presidency and General Management of the Frigidaire Corporation, another Division of the General Motors Corporation, the latter concern manufacturing iceless electric refrigerators.



J. PARKER B. FISKE

Mr. Fiske has made many inventions in the electrical and clay working field, as well as in farm lighting and refrigerating apparatus, and has taken out about fifty patents. "Tapestry" brick was created and introduced by Mr. Fiske about ten years ago.

Mr. Fiske was the originator of the Building Brick Association of America and one of the leading organizers of the American Face Brick Association and other coöperative societies for the promotion of trade coöperation.

He is a charter member of the AMERICAN CERAMIC SOCIETY and a member of the Engineers' Club of New York, American Society of Automotive Engineers, American Society of Refrigerating Engineers and Technology Club of New York.

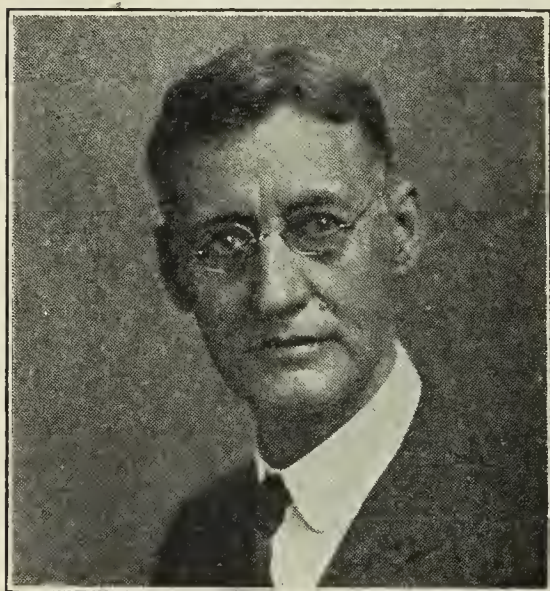
W. D. Gates

W. D. Gates was born at Ashland, Ohio, in 1852. He was graduated from Wheaton College in 1875, and was admitted to the Illinois Bar in 1879.

For a short while, he practised law in Chicago, but he soon became interested in clay, and started manufacture at Terra Cotta, McHenry County, Illinois, establishing

the station there and originating the American Terra Cotta & Ceramic Company. This Company was incorporated in 1887.

Mr. Gates is a charter member of the AMERICAN CERAMIC SOCIETY, and at the time of the organization of the SOCIETY, acted as temporary chairman. He served as President of the SOCIETY in 1905. He was President of the National Brick Manufacturers' Association in 1900, and of the National Terra Cotta Society in 1920.



WM. D. GATES

connected with the Winkle Terra Cotta Company of St. Louis. At Golden, Colorado, in 1900, he made the first white table ware from native clays to be manufactured west of the Mississippi. In 1906, Mr. Geijsbeek, removed to the Pacific Northwest, where he organized the Northern Clay Company at Auburn, Washington, for the manufacturing of Terra Cotta. In 1910, his connection with this Company was severed, and he opened an engineering office under the name of the Geijsbeek Engineering Company, making a specialty of clay works engineering in the Pacific Northwest states.

Mr. Geijsbeek is a charter member of the AMERICAN CERAMIC SOCIETY, and served as Vice-President of the SOCIETY during 1906-1907. He is also a member of the National Brick-makers' Association, is a licensed practicing engineer in the State of Oregon, and for seven years has acted as Secretary and Treasurer of the Oregon Clayworkers' Association. Mr. Geijsbeek has contributed various papers to the *Transactions of the American Ceramic Society*, and also to leading clay journals.

Samuel Geijsbeek

Samuel Geijsbeek of Seattle, Washington, was born in Holland, and received his technical education at the Royal German Technical University, Berlin-Charlottenberg, and at the Ohio State University, Columbus, Ohio. He was graduated from the latter institution in 1896. Mr. Geijsbeek's grandfather was one of the foremost roofing tile manufacturers in Holland.

For several years, Mr. Geijsbeek was con-



SAMUEL GEIJSBEEK

E. E. Gorton

E. E. Gorton attended the Ohio State University and spent four years with the American Terra Cotta and Ceramic Company and then did special work in the ceramic line in various parts of the United States for two years. He later located in New York where he was Treasurer and Manager of the W. A. Underhill Brick Company. Mr. Gorton is now in the oil business.

Mr. Gorton was a charter member of the AMERICAN CERAMIC SOCIETY and with Mr. Wheeler assisted in drawing up the By-Laws and Constitution of the SOCIETY. His recent years have not been connected with the ceramic business.

Karl Langenbeck

Karl Langenbeck was born in Cincinnati, Ohio, on October 7, 1861. He was graduated from the College of Pharmacy in Cincinnati in 1882 and attended laboratory classes and lectures on chemistry at the University of Cincinnati. He later attended the Federal Polytechnic School in Zürich, Switzerland and the Kgl. Technische Hochschule in Berlin.

In 1885 and 1886 Mr. Langenbeck was chemist and superintendent of the Rookwood Pottery in Cincinnati. His experiments at this time led to the discovery of conditions of crystalline separation of ferric chromate from ferric-lead glazes in aventurine-like formation called Rookwood "Tiger eye" ware.

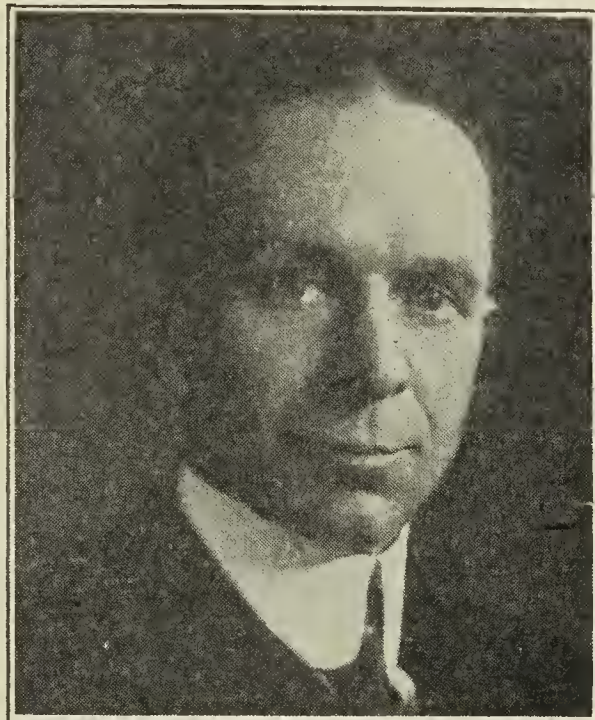
Mr. Langenbeck promoted the Avon Pottery in Cincinnati and opened ball clay deposits of Western Kentucky for commercial use at the instance of the Kentucky Geological Survey. Samples made from this clay in 1887 are now in the museum at Frankfort, Kentucky.

During 1888 and 1889 Mr. Langenbeck did chemical laboratory work, serving as Chemist to the City Health Officer and was also Professor of Chemistry in Miami Medical College.

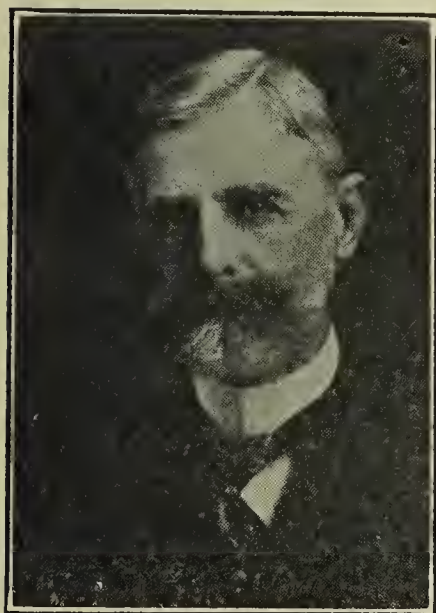
From 1890 until 1893 he was chemist for the American Encaustic Tiling Company of Zanesville, Ohio, where he introduced parian vitreous bodies to take the place of "smeared" white and light colored tile used exclusively in American and English manufacture until then. Dust inlaid encaustic tile and Seger's cones for firing control were introduced. The Mosaic Tile Company of Zanesville, Ohio, was also promoted by Mr. Langenbeck.

In his research work, Mr. Langenbeck discovered the zinc oxide-feldspar glaze and introduced its use for stoneware. He also applied mechanical analysis to molding sands and started the "milled sand" industry of the country. He organized better technical, commercial and decorative methods in numerous factories and made a study of the causes of decay in wood floors. He popularized the hygienic importance of tiling for the tile industry. Other phases of his work were physiological studies in the rhythm of nutrition and oxidation and studies in soil chemistry for fertilizer industries. Among his writings is the "Chemistry of Pottery."

Mr. Langenbeck is at the present time with the United States Tariff Commission. He served as President of the AMERICAN CERAMIC SOCIETY during 1900-1901.



ELMER E. GORTON



KARL LANGENBECK

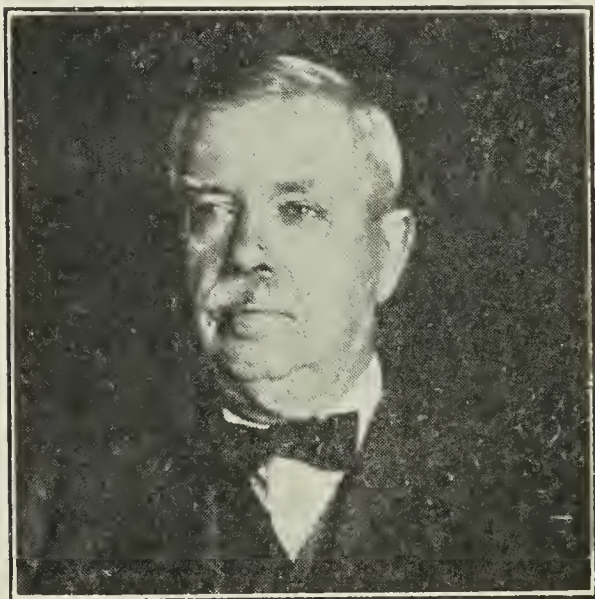
Ellis Lovejoy

Ellis Lovejoy was born in Columbus, Ohio, in 1860. His early education was received in country and village schools and from 1875 to 1877 he attended normal school. For three years following this Mr. Lovejoy taught country school and in the spring

of 1879 matriculated in Ohio State University. His degree in Mining Engineering was received in 1885. During the years 1883 and 1885-1886 he served as assistant in the field work of the Ohio Geological Survey.

In 1886-1887 Mr. Lovejoy was chemist for the Columbus Brick and Terra Cotta Company, Union Furnace, Ohio, and was superintendent of this company until 1907. This Company had a compartment continuous kiln, the first to be built in Ohio and as far as is known the third to be used in the United States. The equipment consisted of dry press brick machines, the first to be introduced in Ohio and east of St. Louis.

The products of this kiln were fire bricks using local plastic fire clay, flint clays from Olive Hill, Kentucky, and from Vinton County, Ohio. A fine sand product was also in use which was made from a sand rock formerly quarried and widely used in charcoal iron furnace hearths. These products manufactured in 1886-1887 were the first dry pressed fire brick products to be made in the county.



ELLIS LOVEJOY

This plastic fire brick product was then made into a face building brick of light buff shade used for the first time in a residence, and other shades of buff and a color designated as terra cotta was produced.

One of the problems widely discussed was the cause of efflorescence on walls and when this fault was overcome the Union Furnace product was given a decided advantage in the market.

The progenitor of the recent pulschrome product was developed in a red brick with black splotches. This together with a white enameled brick was worked out under the immediate supervision of a student from Professor Orton's school of ceramics.

In 1903-1904, Mr. Lovejoy was manager of the Imperial Clay Company of New Lexington, Ohio. The first wire-cut texture face brick were produced here which opened a wider field in face brick than any previous development.

The years 1904-1906 were spent as consulting engineer and from that time until 1916 Mr. Lovejoy was treasurer and subsequently president of the Richardson-Lovejoy Engineering Company. This Corporation was dissolved and its charter surrendered in 1916 and since that date Mr. Lovejoy has been employed in consulting work.

Mr. Lovejoy is the author of "Scumming and Efflorescence," "Drying Clay Wares," and "Burning Clay Wares."

He served as President of the AMERICAN CERAMIC SOCIETY during 1913-1914 and was Treasurer of the SOCIETY from 1906-1913 and is also a charter member. Since 1886 he has been a member of the American Institute of Mining and Metallurgical Engineers.

Ernest Mayer¹

Ernest Mayer was born in Burslem, Staffordshire, England, October 4, 1857, the son of Jos. Mayer of the pottery firm of T. J. and J. Mayer, Dale Hall Works, Burslem. His father, Jos. Mayer, was known in his time as an expert in the manufacture of pottery, and frequently referred to as the successor of Josiah Wedgwood as an authority on the subject.

¹ Died Dec. 13, 1920.

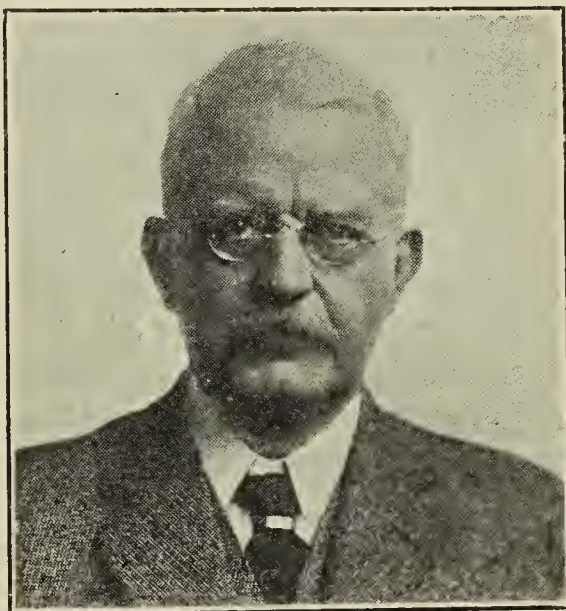
Ernest Mayer's first connection with the Pottery Industry was in the capacity of an apprentice with the firm of G. W. Turner & Sons, Tunstall, England, where about the same time Mr. W. H. Grindley, the well-known Staffordshire manufacturer was similarly beginning his career. Later he was connected with the firm of Clemenston Brothers, Hanley, England. He first attracted some notice in the trade by the publication of a pamphlet on an improved method of mixing bodies wet. He was also about this time the originator of a new kind of Jigger. Mr. Mayer came to America in 1878 and spent a year in the office of his two brothers, then engaged in the business of importing crockery in New York City and then became superintendent for a time of a pottery in Baltimore.

In 1881, together with his brother Joseph Mayer, he established what is known today as the Mayer China Company at Beaver Falls, Pa., one of the best known producers of hotel china in this country, and for the past forty years he had been actively in charge of the manufacturing end of that business.

As master of all the complicated details of pottery manufactory, and particularly in the chemistry of pottery, perhaps no man living today excelled him. His abilities were recognized among manufacturing potters, universally, not only in this country but in England as well, and his counsel and advice will be greatly missed by all his associates in the trade.

High above his knowledge and skill in his chosen art, however, Ernest Mayer will be appraised and remembered for his character as a man. Totally without pretense, unassuming, even backward, he yet possessed a strong personality that impressed, and had the courage to always stand by his convictions.

Mr. Mayer was a charter member of the AMERICAN CERAMIC SOCIETY and was elected Vice-President the first year of the organization. He was Vice-President again in 1901-1902 and served as President in 1902-1903.



ERNEST MAYER

H. C. Mueller

H. C. Mueller was born in 1854 at Rodach, near Saxe-Coburg, Germany. In his early years he studied as a sculptor in Nuremburg and Munich, modeling and carving wood and stone. After leaving the art schools he traveled, working in his profession as a sculptor. He served for two years in the German Army and shortly afterward immigrated to America and located in Cincinnati where he worked at carving marble, lithographing, modeling and later in cement work. During this period Mr. Mueller made models for the Kensington Tile Works and also for the Matt Morgan Art Pottery. He later modeled at the Brighton Terra Cotta Factory in Indianapolis and when the State Capitol of that State was being erected he was engaged to make models for the statuary of the façade of the building and other decorative features in the pediments and gables. He also carved and made models for the interior



H. C. MUELLER

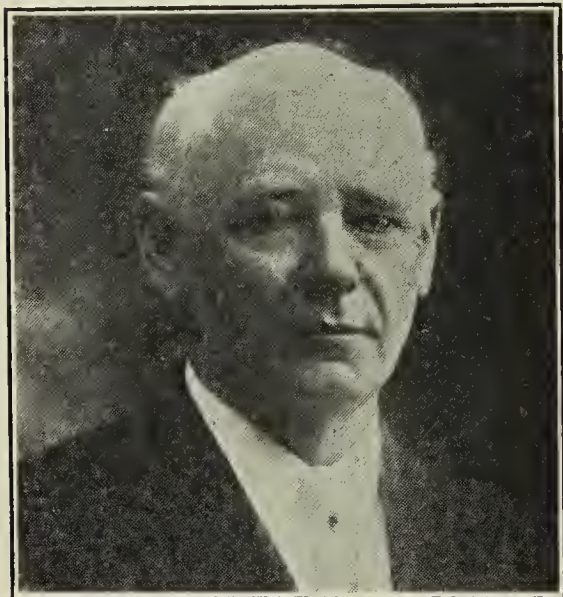
stucco work. Following this period he was employed by the United States Encaustic Tiling Company making designs and models for mantel facings and for ten years worked with the American Encaustic Tiling Company. During this period he also engaged in mechanic technical work, inventing processes of inlaying mosaics for which he received a John Scott medal of the Franklin Institute of Philadelphia. With Mr. Karl Langenbeck he organized the Mosaic Tile Company of Zanesville, Ohio, and after seven years took over the management of the National Tile Company. He also worked for six years with the Robertson Art Tile Company of Morrisville, Pa. Mr. Mueller later organized the Mueller Mosaic Company of Trenton, N. J., in which he continues principally in original artistic work.

Mr. Mueller was a charter member of the AMERICAN CERAMIC SOCIETY.

Edward Orton, Jr.

Edward Orton, Jr., was born in 1863, of New England and New York lineage. His people were farmers with a good sprinkling of educators, clergy and professional men. His father was the first President of the Ohio State University. Edward, Jr. was graduated from that school in 1884 as a Mining Engineer, and began his professional work as a surveyor in the coal mines.

After a few months of this, he entered the metallurgical field, serving as draftsman in steel works, chemist in blast furnaces and open hearth steel works, finally becoming superintendent of blast furnaces in Ohio and Virginia. In this latter capacity, he was the first in the United States (1888) to produce ferrosilicon, or iron alloys containing guaranteed high percentages of silicon.



COL. EDWARD ORTON, JR.

In 1890, he left the metallurgical field, to enter clay manufacture, serving as superintendent of paving brick plants in Ohio and Kentucky, and as special contributor on clays and manufacture of clay products for the Ohio Geological Survey. In 1893 he agitated the founding of a technical school for the study of clays and clayworking upon a scientific and engineering basis, and in 1894 succeeded in inducing the Legislature of Ohio to establish such a school, the first of its kind in the United States, in the Ohio State University. He became the first Director and remained the guiding genius of the school for twenty-two years (1916).

As a writer and research man in the ceramic field, Professor Orton has a goodly list of articles and investigations to his credit. He has been of possibly greater value in inspiring and directing the researches and publications of others, for which he cannot of course be given credit in his own bibliography.

The idea of putting clayworking and ceramic operations in general upon a scientific basis, comparable in accuracy to those of metallurgy, under the title of Ceramic Engineering, was accepted slowly and reluctantly by the industries concerned, and also by the technical and engineering schools. Professor Orton has had the satisfaction of seeing his idea take firm root, and become an accepted branch of engineering training in a number of strong universities in the United States and in England.

He was the promoter and active spirit in organizing in 1898 the AMERICAN CERAMIC SOCIETY, which has become the internationally known exponent of the Ceramic Engineering profession. He served as Secretary of this organization for twenty years, until 1918, and as editor of its first ten volumes of the *Transactions*.

In 1896 he began the manufacture upon a small scale of Standard Pyrometric cones, a device for regulating and controlling the firing process in kilns and industrial furnaces. This business grew steadily until a factory had to be erected in 1906 to take care of it. Professor Orton has owned, supervised and managed this business ever since its inception, without conflict with his educational and professional duties, and for some years it has been his chief financial dependence.

In 1899, upon the death of his father, Dr. Edward Orton, he succeeded him as State Geologist of Ohio, which position he filled until 1907. During his administration he reorganized the Survey, and issued two volumes and nine bulletins of reports, mostly upon economic geology.

In 1902, Professor Orton was made Dean of the College of Engineering, of the Ohio State University, and held this position with brief intermission until 1916.

For many years an ardent believer in the importance of military training, and foreseeing the part that the United States would play in the World War, Dean Orton took the training in 1916 in the Citizen's Military Training camp at Plattsburgh, New York, and was commissioned a Major in the Quartermasters Reserve Corps in January, 1917. Upon the opening of hostilities in April, 1917, he was ordered into active duty and assigned to the Motor Transport branch. He was promoted to Lieutenant Colonel in September, 1918. For his exceptionally meritorious services in the standardization of motor equipment he was awarded the Distinguished Service Medal. He was discharged in June, 1919, and at once re-commissioned as a Colonel of the Officers Reserve Corps.

Returning to Columbus in 1919, Colonel Orton did not go back into educational work, but resumed supervision of his manufacturing business. In addition he bought and operated a farm, and afterwards soon began devoting his spare time to various forms of public service for the Chamber of Commerce and other organizations.

He was elected President of the Columbus Chamber of Commerce in 1921, and again in 1922. Under his administration the Chamber has enjoyed a period of vigorous constructive work and excellent material progress upon numerous public projects has been made.

Colonel Orton believes firmly in the engineering education, with its inflexible curriculum and its merciless insistence upon reasoning only from demonstrable facts of science, as the best foundation for the development of mental power, no matter what profession may be the ultimate goal.

James Pass¹

James Pass was born in Burslem, Staffordshire, England, in 1856, and came to this country with his parents in 1863. At the age of thirteen he was apprenticed to a pottery maker at Trenton, N. J., and later when the family removed to Syracuse, N. Y., he became foreman under his father at the Onondaga Pottery. After three years spent in the West he returned to the Onondaga Pottery as General Manager. Mr. Pass's appreciation of the value of the application of scientific methods in the ceramic industries was evidenced by his attendance as a student for a year at Syracuse University where he took a special course in Chemistry.

Mr. Pass was a charter member of the AMERICAN CERAMIC SOCIETY and he also belonged to other technical organizations.

¹ Died October, 1913.

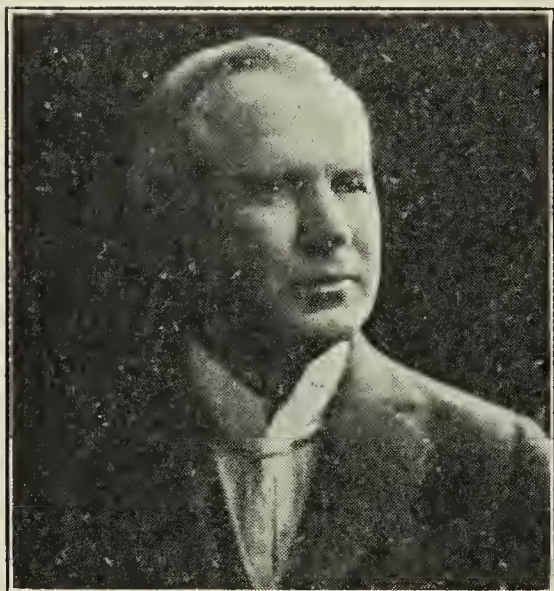


JAMES PASS

Willard Durant Richardson

W. D. Richardson was born in Georgetown, N. Y., August 28, 1857. He was graduated from Colgate University in 1879 with a degree of A.B. and in 1884 received the degree of A.M. from the same Institution. Following his graduation at Colgate, Mr. Richardson was Principal of the High School, Chattanooga, Tenn., and later while taking a course in mining engineering at Columbia University he taught in the public evening schools of Brooklyn. After leaving Columbia he worked as an analytical chemist in the laboratory of Dr. Sloane where he first became interested in clays. Later, while teaching in Minneapolis he spent three summers in dry-press brick plants at Coon Creek, Monticello and Rush City.

In 1888 Mr. Richardson came to Ohio from St. Louis for the purpose of building a face brick plant at North Baltimore which he had charge of for five years. He was later General Manager of brick companies at Cleveland and Shawnee, Ohio and Hebron, North Dakota, making face brick, paving brick and hollow building tile. After this for five years he was alone in Columbus at the head of his own brick works engineering business and for five years he was associated with Mr. Ellis Lovejoy and the Richardson-



W. D. RICHARDSON

Lovejoy Engineering Company. During the War Mr. Richardson acted as ceramic engineer for the Shipping Board of the United States and following the signing of the Armistice he established the Ceramic Engineering Company in Columbus of which he is President.

Mr. Richardson has published numerous articles and pamphlets on brick manufacture and has taken out several patents on improved equipment for the clay industries. The best known among these latter is the "Richardson Continuous Compartment Kiln Fired with Producer Gas."

Mr. Richardson was President of the AMERICAN CERAMIC SOCIETY, 1906-1907, and was a charter member. He is also a member of the National Brick Makers' Association and the English Ceramic Society, being a past President of the former Association. He is a member of the Committee on Technical Investigations of the National Brick Makers' Association and AMERICAN CERAMIC SOCIETY Representative on the American Society for Testing Materials Committee D-14.

H. Ries

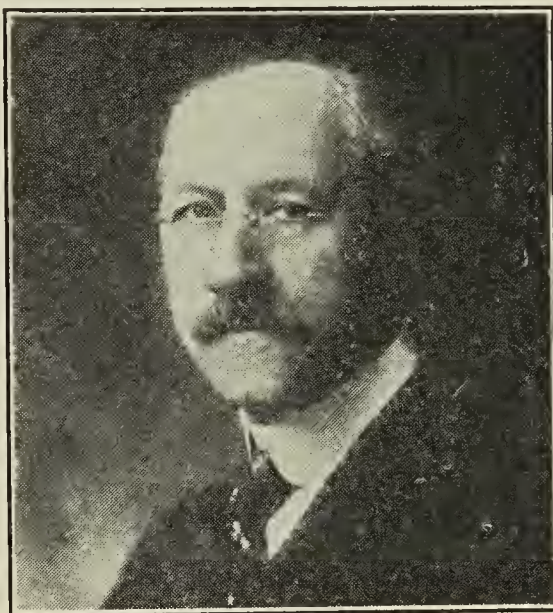
H. Ries, Professor of Geology and Head of the Department of Geology, Cornell University, Ithaca, N. Y., was born in Brooklyn, N. Y., April 30, 1871. He was graduated from Columbia University with the degrees of Ph.B. in 1892, M.A. in 1894 and Ph.D. in 1896. From 1893 to 1895, Dr. Ries held a University Fellowship at Columbia University and from 1897 to 1900 held the Barnard Fellowship from the same Institution. The work under the latter Fellowship was done for the special purpose of investigating the geology and properties of clay. While thus engaged he spent a year in Europe studying the foreign clay deposits and working with Prof. Witt of Berlin.

Ever since his graduation Dr. Ries has been especially interested in the subject of the geology of clay and its uses.

In addition to being the author of numerous papers on this subject he has prepared special reports for State Geological Surveys on the clays of Alabama, New York,

Maryland, Virginia, Florida, Louisiana, Michigan, North Carolina, Texas and New Jersey. He has written several reports on the same subject issued by the U. S. Geological Survey, the last one of these on the "High Grade Clays of the United States," being prepared during the War in connection with the War Minerals Work carried on by the Government. Other writings of Dr. Ries are "Clay, its Occurrence, Properties and Uses," "Economic Geology," and (with H. Laighton) "History of the Clay Working Industry of the United States." The latter was prepared under the auspices of Carnegie Institute. Dr. Ries was also engaged by the Canada Geological Survey to investigate the clay resources of Canada, the results of which were embodied in several reports.

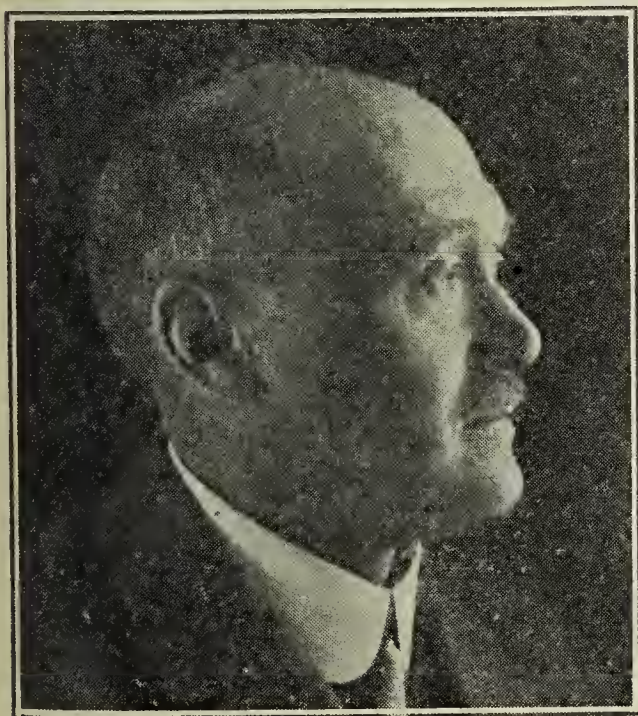
Dr. Ries is Chairman of the Non-Metallic Minerals Committee of the American Institute of Mining and Metallurgical Engineers. He is a charter member of the AMERICAN CERAMIC SOCIETY, English Ceramic Society, American Institute of Mining Engineers, Canadian Mining Institute, and the Geological Society of America. During 1910 and 1911 Dr. Ries was President of the AMERICAN CERAMIC SOCIETY. He is a member of the Executive Committee of Committee in charge of Investigation of Molding Sands, acting under the National Research Council and American Foundrymen's Association.



H. RIES

Edward C. Stover

Edward C. Stover for the past twenty-four years has been Treasurer of the School of Industrial Arts at Trenton, N. J. He is a charter member of the AMERICAN CERAMIC SOCIETY, and served as President during 1903-1904. Mr. Stover is also a charter member of the Society Ceramique of France, and also of the English Ceramic Society of the Staffordshire pottery district of England. He acted as chairman of the publication committee of the works of Herman Seger.



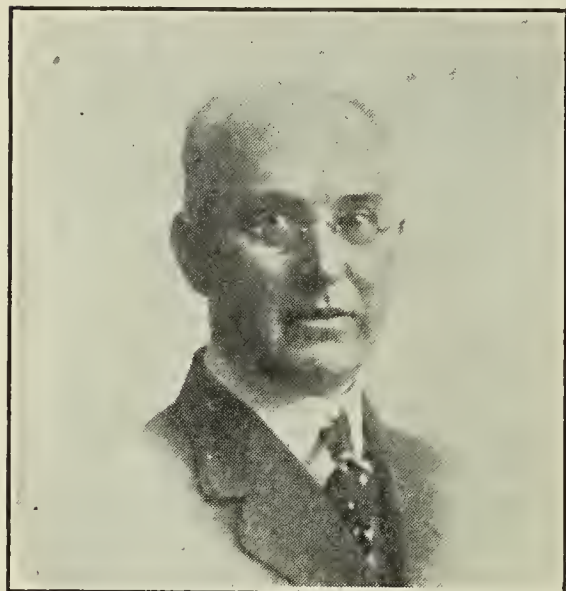
EDWARD C. STOVER

Francis William Walker

Francis W. Walker was born at Industry, Pa., on May 7, 1855. After completing his general education at the Kenwood School at New Brighton, Pa., he studied pharmacy first at the Maryland College of Pharmacy, Baltimore, and later at the Pittsburgh College of Pharmacy (now the University of Pittsburgh), where he finished his professional education and was graduated with the degree of Ph.G. in 1882. Early in the following year he established himself as a pharmacist in New Brighton and followed his profession until 1887.

In 1886, Mr. Walker organized the Beaver Falls Art Tile Company, at Beaver Falls, Pa., built a plant and began operations in 1887, and acted as its General Manager

until 1916, when he relinquished this position to his son. He served also as the Secretary-Treasurer of this company from its beginning until 1920, when he was made President.



F. W. WALKER

In 1893 he organized the first association of tile manufacturers, and served as its Secretary for a number of years. Mr. Walker is now the Executive Secretary of the Associated Tile Manufacturers and the Tile Manufacturers' Credit Association, a position which he has held since 1903.

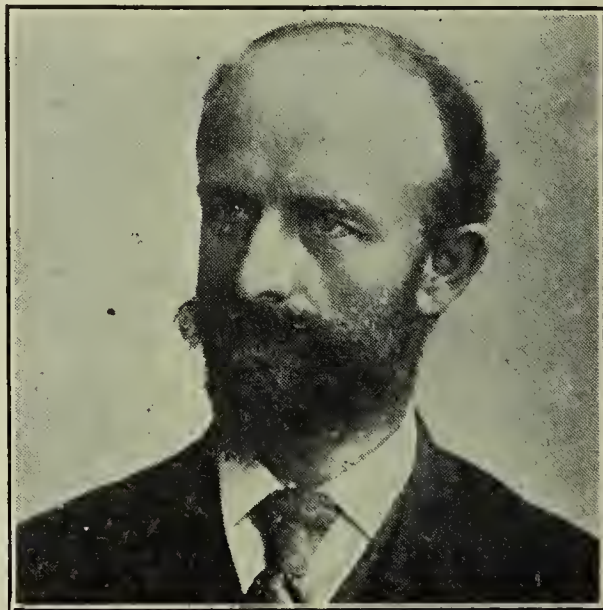
He is also President of the Robert Rossman Company of New York, a tile jobbing and importing house; the Vice-President of the American Vitrified Products Company, and Vice-President of the Pennsylvania State Chamber of Commerce.

Mr. Walker is an active member of the AMERICAN CERAMIC SOCIETY, being one of its organizers and served as its sixth President during 1904-1905. He was also Vice-President, 1902-1903.

H. A. Wheeler

H. A. Wheeler was born in Brooklyn, N. Y., in 1859, and was graduated in 1880 as a mining engineer from Columbia University. Following his graduation, he spent one year in Utah on the United States Geological Survey, one year on location work in Utah and Colorado for the Denver, Rio Grande and Western Railroad, and a third year in charge of the Ely Copper Mine, at Ely, Vermont. He then joined the Mining Department of Washington University, St. Louis, Missouri, where for twelve years he had charge of the Department of Mining and Geology. Since 1893, he has been in consulting practice as ceramist and mining engineer in St. Louis.

While at Washington University, Mr. Wheeler undertook the field and physical study of the clays of Missouri for the Missouri Geological Survey, which material was subsequently published as Volume II of the Missouri Survey Reports. In 1897, he built and operated the plant of the Standard Tile Company, the first roofing tile plant west of the Mississippi. Mr. Wheeler has made frequent contributions to the technical press. Although from 1895 to 1910, he was quite active as a consulting ceramist, his recent years have been devoted to mining engineering and the geology of oil.



H. A. WHEELER

Mr. Wheeler served the AMERICAN CERAMIC SOCIETY as its first President and took a very active part in its affairs and earlier history. More recently, the demands of other interests have prevented his participating in the active affairs of the SOCIETY.

Werner Hermann Zimmer

W. H. Zimmer was born at Gera, Turingen, Germany in 1857. He studied at the Universities of Jena and Berlin from 1885 until 1890 and passed, *cum laude*, his exami-

nation as Doctor of Philosophy at Berlin where he remained as Assistant in the first laboratory of chemistry of the University. In 1891 he applied himself to ceramics and studied at the Versuchsanstalt of the Royal Porcelain Works, Charlottenburg. In the same year he left for the United States to become Superintendent and later Manager of the Ohio Valley China Company, Wheeling, W. Va. After this Company closed down he became connected with the Wheeling Potteries where he remained until 1901. At this time he returned to Germany to become Editor of the *Sprechsaal* in Coburg. During this Coburg period he was also technical advisor for the Annawerk near Coburg where he established the manufacturing of sanitary ware. Since July, 1907, Dr. Zimmer has been connected with the Havilands of New York and Limoges. After visiting Limoges he built the factory Johann Haviland in Waldershof, Bavaria, for the manufacturing of porcelain dinner- and hotel-ware. Since that time Dr. Zimmer has remained in Waldershof although his family resides in this country.



W. H. ZIMMER

Dr. Zimmer was a charter member of the SOCIETY.

OFFICERS OF THE AMERICAN CERAMIC SOCIETY FROM 1899-1922

1899-1900

President, H. A. Wheeler	Council
Vice-Pres., Ernest Mayer	H. A. Wheeler, E. Mayer,
Secretary, Edward Orton, Jr.	E. Orton, Jr., S. G. Burt,
Treasurer, Stanley G. Burt	W. H. Zimmer, S. Geijsbeek,
	C. F. Binns

1900-1901

President, Karl Langenbeck	Council
Vice-Pres., C. F. Binns	K. Langenbeck, C. F. Binns,
Secretary, Edward Orton, Jr.	E. Orton, Jr., S. G. Burt,
Treasurer, Stanley G. Burt	S. Geijsbeek, W. H. Zimmer,
	H. A. Wheeler

1901-1902

President, C. F. Binns	Council
Vice-Pres., E. Mayer	C. F. Binns, E. Mayer,
Secretary, Edward Orton, Jr.	E. Orton, Jr., S. G. Burt,
Treasurer, Stanley G. Burt	S. Geijsbeek, H. A. Wheeler,
	A. V. Bleininger

1902-1903

President, Ernest Mayer	Council
Vice-Pres., F. W. Walker	E. Mayer, F. W. Walker,
Secretary, Edward Orton, Jr.	E. Orton, Jr., S. G. Burt,
Treasurer, Stanley G. Burt	H. A. Wheeler, A. V. Blein-
	inger, A. F. Hottinger

LIST OF OFFICERS OF THE

1903-1904

President,	E. C. Stover	Council
Vice-Pres.,	H. Ries	E. C. Stover, H. Ries,
Secretary,	Edward Orton, Jr.	E. Orton, Jr., S. G. Burt,
Treasurer,	Stanley G. Burt	A. V. Bleininger, E. E. Gorton, A. F. Hottinger

1904-1905

President,	F. W. Walker	Council
Vice-Pres.,	A. V. Bleininger	F. W. Walker, A. V. Bleininger, E. Orton, Jr.,
Secretary,	Edward Orton, Jr.	S. G. Burt, A. F. Hottinger,
Treasurer,	Stanley G. Burt	E. E. Gorton, E. C. Stover

1905-1906

President,	W. D. Gates	Trustees
Vice-Pres.,	Ellis Lovejoy	E. E. Gorton, E. C. Stover,
Secretary,	Edward Orton, Jr.	W. M. Fickes
Treasurer,	Stanley G. Burt	

1906-1907

President,	W. D. Richardson	Trustees
Vice-Pres.,	S. Geijsbeek	E. C. Stover, W. M. Fickes,
Secretary,	Edward Orton, Jr.	A. S. Watts
Treasurer,	Ellis Lovejoy	

1907-1908

President,	S. G. Burt	Trustees
Vice-Pres.,	R. C. Purdy	W. M. Fickes, A. S. Watts,
Secretary,	Edward Orton, Jr.	L. Parker
Treasurer,	Ellis Lovejoy	

1908-1909

President,	A. V. Bleininger	Trustees
Vice-Pres.,	Chas. Weelans	A. S. Watts, L. Parker,
Secretary,	Edward Orton, Jr.	C. W. Parmelee
Treasurer,	E. Lovejoy	

1909-1910

President,	Ross C. Purdy	Trustees
Vice-Pres.,	Arthur S. Watts	L. Parker, C. W. Parmelee,
Secretary,	Edward Orton, Jr.	H. E. Ashley
Treasurer,	Ellis Lovejoy	

1910-1911

President,	H. Ries	Trustees
Vice-Pres.,	R. R. Hice	C. W. Parmelee, H. E. Ashley,
Secretary,	Edward Orton, Jr.	W. J. Cannan
Treasurer,	Ellis Lovejoy	

1911-1912

President,	Charles Weelans	Trustees
Vice-Pres.,	L. E. Barringer	H. E. Ashley, (E. Mayer, served Ashley's unexpired term), W. J. Cannan, J. P. B. Fiske
Secretary,	Edward Orton, Jr.	
Treasurer,	Ellis Lovejoy	

1912-1913

President, Arthur S. Watts	Trustees
Vice-Pres., C. W. Parmelee	W. J. Cannan, J. P. B. Fiske,
Secretary, Edward Orton, Jr.	H. P. Humphrey
Treasurer, Ellis Lovejoy	

1913-1914

President, Ellis Lovejoy	Trustees
Vice-Pres., Adolph F. Hottinger	J. P. B. Fiske, H. P. Humphrey,
Secretary, Edward Orton, Jr.	F. W. Walker
Treasurer, Herford Hope	

1914-1915

President, C. W. Parmelee	Trustees
Vice-Pres., D. T. Farnham	H. P. Humphrey, F. W.
Secretary, Edward Orton, Jr.	Walker, G. H. Brown
Treasurer, Herford Hope	

1915-1916

President, R. R. Hice	Trustees
Vice-Pres., R. T. Stull	F. W. Walker, G. H. Brown,
Secretary, Edward Orton, Jr.	H. F. Staley
Treasurer, Herford Hope	

1916-1917

President, L. E. Barringer	Trustees
Vice-Pres., F. K. Pence	G. H. Brown, H. F. Staley,
Secretary, Edward Orton, Jr.	A. F. Hottinger
Treasurer, Herford Hope	

1917-1918

President, G. H. Brown	Trustees
Vice-Pres., Charles E. Jackson	E. T. Montgomery, H. F. Staley,
Secretary, Edward Orton, Jr.	A. F. Hottinger, L. E. Barringer
Treasurer, Ralph K. Hursh	

1918-1919

President, H. F. Staley	Trustees
Vice-Pres., A. F. Greaves-Walker	E. T. Montgomery, R. D. Landrum,
Secretary, C. F. Binns	A. F. Hottinger, G. H. Brown,
Treasurer, R. K. Hursh	L. E. Barringer

1919-1920

President, R. T. Stull	Trustees
Vice-Pres., R. H. Minton	G. H. Brown, H. F. Staley,
Secretary, C. F. Binns	R. D. Landrum, M. F. Beecher,
Treasurer, R. K. Hursh	E. T. Montgomery

1920-1921

President, R. H. Minton	Trustees
Vice-Pres., E. T. Montgomery	R. D. Landrum, M. F. Beecher,
Secretary, C. F. Binns	F. H. Riddle, H. F. Staley,
Treasurer, R. K. Hursh	R. T. Stull

1921-1922

President, F. K. Pence
 Vice-Pres., F. B. Ortman
 Secretary, C. F. Binns
 Treasurer, R. K. Hursh

Trustees

M. F. Beecher, F. H. Riddle,
 R. M. Howe, R. T. Stull,
 R. H. Minton

1922-1923

President, F. H. Riddle
 Vice-Pres., E. Ward Tillotson, Jr.
 Secretary, Ross C. Purdy
 Treasurer, Ralph K. Hursh

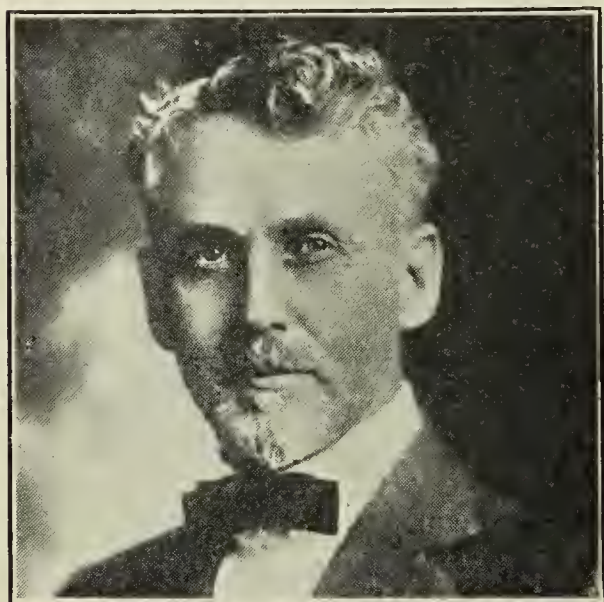
Trustees

F. B. Ortman, R. M. Howe,
 B. E. Salisbury, R. H. Minton,
 F. K. Pence

PAST AND PRESENT OFFICERS¹

Ross C. Purdy

Ross C. Purdy was born in Jasper, New York, in 1875, and took his degree of Ceramic Engineer in 1908 at the Ohio State University. From 1899 until 1901, he was chemist and assistant superintendent of the Mosaic Tile Company, and for a year was chemist and foreman of the glazing and burning departments of the Roseville Pottery Company. For three years, Mr. Purdy was Assistant in Ceramics at the Ohio State University, and from 1905 until 1907, he was instructor at the University of Illinois, where he organized the Department of Ceramics. During 1907-1908 he was Assistant Professor of Clay Working and Ceramics at Ohio State University and in 1909



ROSS C. PURDY

was Associate Professor of Ceramic Engineering, and from 1909 until 1911, Professor of the same Department. From 1911 until 1919, Mr. Purdy was director of the research laboratories of Norton Company, Worcester, Massachusetts. Since 1919, he has been Vice-President and Assistant General Manager of the Dover Manufacturing Company at Dover, Ohio. From 1905 until 1907, Mr. Purdy was also ceramist for the Illinois Geological Survey. In July, 1921, he was made Organizing Secretary of the AMERICAN CERAMIC SOCIETY, with offices located at the Ohio State University, Columbus, Ohio.

During 1909-1910, Mr. Purdy was President of the AMERICAN CERAMIC SOCIETY, and in 1907-1908 was Vice-President. He was Chairman of the Membership Committee during 1916, 1917 and 1918, and Editor of Vol. 13 of the *Transactions* in 1911.

In February, 1922, he was appointed editor of this *Journal*, which was enlarged, and the new *Bulletin* section with Discussions and Activities of the Society added.

Other organizations to which Mr. Purdy is allied are Sigma Xi and the American Society for Testing Materials, in which Society he serves on the Advisory Council, and also as Chairman of Committee C-8.

Charles Weelans²

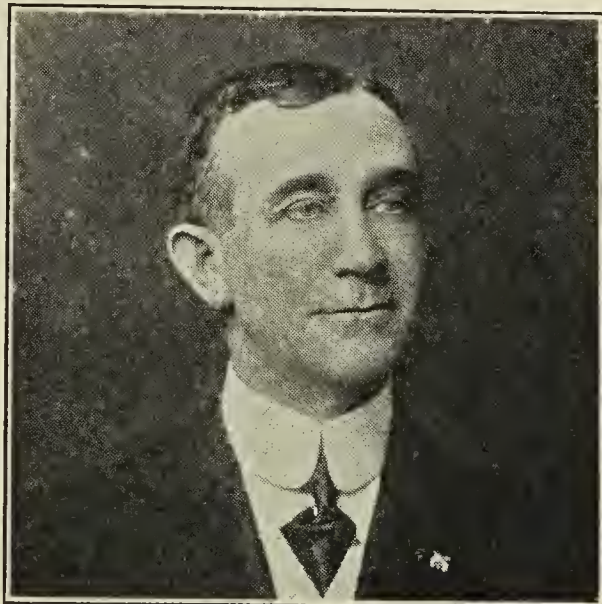
Charles Weelans was born in Barnaby, Yorkshire, England in 1863 and came with his parents to Trenton, N. J., while an infant. At the age of fifteen he was employed

¹ Other than those who are also charter members.

² Died Dec. 12, 1916.

in a pottery and at the age of twenty-five was made superintendent of the Upper Greenwood Pottery. He subsequently was connected with the Trenton Potteries Company and in 1898 established the Monument Pottery. A short while before his death he undertook the building of the Sanitary Manufacturing Potteries at New Brighton, Pa.

Mr. Weelans served as President of the AMERICAN CERAMIC SOCIETY during 1911-1912, and was Vice-President during 1908-1909.



CHARLES WEELANS

Arthur Simeon Watts

A. S. Watts was born in Zanesville, Ohio, in 1876. After his graduation from the Zanesville High School, he took a short course in ceramics at the Ohio State University, and left this University in 1901. In 1909, he attended the Ceramic Fachschule at Bunzlau, Germany, and during 1910-1911, the Charlottenburg Technische Hochschule. From 1901 until 1909 he had professional connections with the F. M. Locke Insulator Manufacture, Victor, N. Y., the Bell Pottery Company, Findlay, Ohio, and the New Lexington Insulator Company, New Lexington, Ohio. During 1912-1913, he served as technologist with the United States Bureau of Mines.

In 1913 Professor Watts became Professor of Ceramic Engineering at the Ohio State University, which position he still retains. Since 1914, he has been at the head of this Department.

Professor Watts was editor of the *Transactions of the American Ceramic Society*, 1914-1917, inclusive, and was president of the SOCIETY during 1912-1913. He has been



ARTHUR S. WATTS

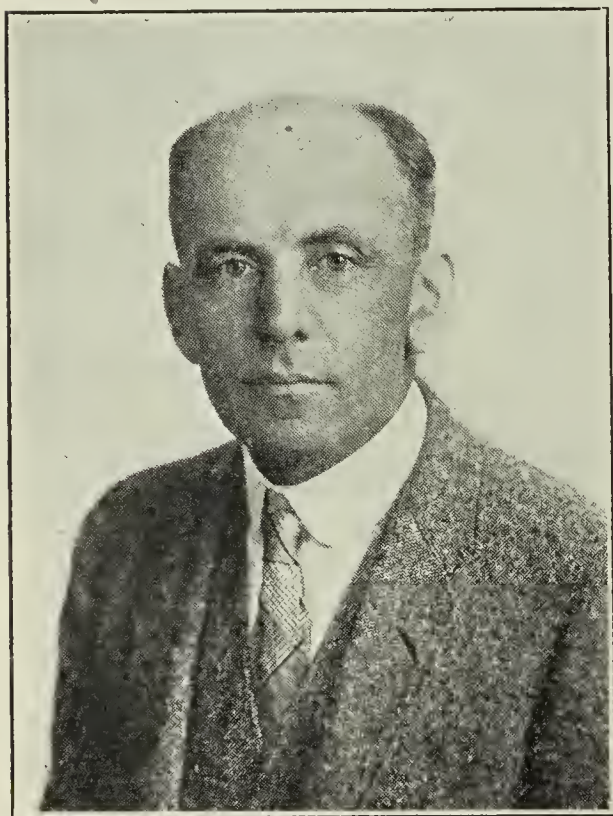
an associate contributor to Mineral Industry "Annual" since 1914, and from 1913-1917 acted as private counsel on porcelain for the Westinghouse Electric & Manufacturing Company. Since 1917, he has carried on a general consulting practice in addition to his teaching position. Professor Watts is a member of Sigma Xi and the American Society for Testing Materials. He has contributed numerous articles to the publications of the AMERICAN CERAMIC SOCIETY, as well as to the United States Bureau of Mines Bulletins.

Cullen W. Parmelee

Cullen W. Parmelee was born in Brooklyn, New York, in 1874. He was graduated from Rutgers College in 1896 with the degree of B.Sc.

and was elected to Phi Beta Kappa in his senior year for scholarship. Five years were spent as chemist with the New York and Boston Dyewood Company of Brooklyn, and in 1901 he returned to Rutgers College as instructor in chemistry. In 1903 Professor Parmelee organized the Department of Clay Working and Ceramics, and was Director of this Department until 1916. He served as Associate Professor of Applied Chemistry from 1905-1908 and as Professor of Ceramics from 1908-1916. In 1916

Professor Parmelee was appointed Professor of Ceramic Engineering at the University of Illinois. He served as acting head of this department during 1918-1919, and was again designated as acting head of the Department for 1922-1923.



C. W. PARMELEE

Professor Parmelee is the author of numerous papers which have appeared in the publications of the AMERICAN CERAMIC SOCIETY and other technical journals.

He has served as Trustee and Vice-President of the AMERICAN CERAMIC SOCIETY, and was President during 1914-1915. Professor Parmelee was Chairman of the Committee appointed to consider the publication by the SOCIETY of a journal, which resulted in the SOCIETY undertaking that enterprise. He is also a member of the Committee on Data of the SOCIETY.

Professor Parmelee organized the New Jersey Manufacturers' Association in 1914, and since 1917 has been Secretary of the Illinois Clay Manufacturers' Association. During 1918, he was appointed District Chief of the Illinois Industrial Furnace Section of the United States Fuel Administration. He is a member of the Joint American Foundrymen's Association, and Division of Engineering, National Research Council Committee on Molding Sand Research.

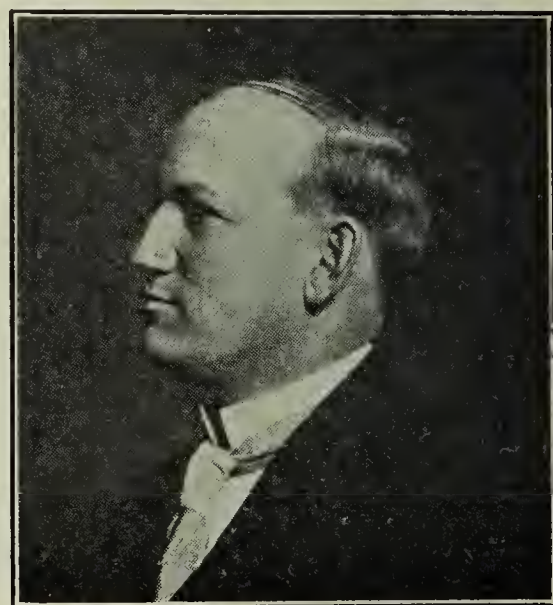
Since 1917, he has been consulting ceramist for the Illinois Geological Survey. Other organizations to which Prof. Parmelee is allied are the American Society for Testing Materials, American Chemical Society, the English Ceramic Society and Sigma Xi.

Richard R. Hice

Mr. Hice was president of the SOCIETY during 1915-16.

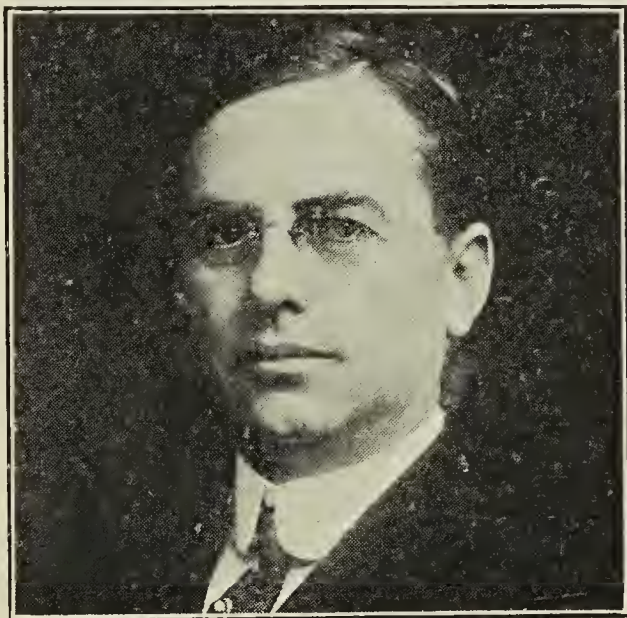
Lawrence Eugene Barringer

Lawrence E. Barringer was born in Washington, D. C., in 1876 and received his degree in Ceramics (M.E.) in 1902. Previous to his college training Mr. Barringer was in the employ of E. M. Freese & Company of Gallion, Ohio, manufacturers of brick and tile machinery. His college course was interrupted also by temporary eye trouble. During the summer of 1897 he was with the Washington Brick Company in Washington, D. C., and the following summer was spent with the American Terra Cotta and Ceramic Company at Terra Cotta, Illinois. Following his graduation Mr. Barringer entered the services of the General Electric Company at Schenectady, New York, as a specialist in the production of porcelain. In 1908 he was made Engineer of Insulations for the General Electric Company. Mr. Barringer has invented a number of useful insulating products and has been granted fourteen patents which have been assigned to the General Electric Company.



RICHARD R. HICE

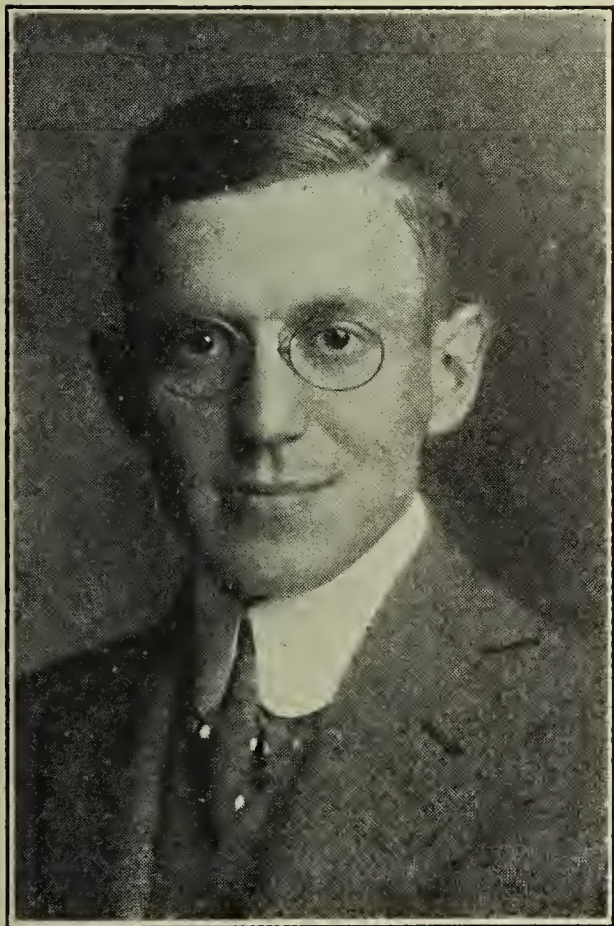
Mr. Barringer served as President of the AMERICAN CERAMIC SOCIETY during 1916-1917. He also served as Chairman of the Committee on Publications from 1918 until 1921 and in this position undertook the launching of the *Journal*. Mr. Barringer has contributed to the technical writings of the *Journal*.



LAWRENCE E. BARRINGER

George Herbert Brown

Professor George H. Brown was born at Miamisburg, Ohio, in 1884, and in 1908 he received his degree of Ceramic Engineer at Ohio State University. From 1910 until 1914, he was Assistant Ceramic Chemist with the Bureau of Standards, and until 1916, was Associate in the same department. In 1916, he became Director of the Department of Ceramics at Rutgers College, New Brunswick, New Jersey, where he is still located. He is also Ceramic Engineer for the Hydraulic Press Brick Company.



PROF. GEORGE H. BROWN

Professor Brown was President of the AMERICAN CERAMIC SOCIETY, 1917-1918, editor of this *Journal* from its first issue, 1918 until 1920, and a Trustee of the SOCIETY from 1914 until 1917. He is also a member of the American Chemical Society and the American Society for Testing Materials.

Homer F. Staley

Homer F. Staley was born at New Philadelphia, Ohio, in 1879. He received his A.B. degree from the Ohio State University in 1904, and in 1909, he studied at Columbia University. From 1905 until 1909, Mr. Staley was superintendent in an enameled iron plant, and from 1909 until 1913, he was Professor in the Department of Ceramic Engineering at the Ohio State University. During 1912-1913, he was also technical director of the Standard Sanitary Manufacturing Company. In 1913, Mr. Staley went to Iowa State University as Professor of Ceramic Engineering, where he remained until 1919, when he became metallurgical ceramist with the Bureau of Standards. In 1921, he

left the Bureau of Standards, and since that time, has been located in New York City with the Metal and Thermit Corporation.

During 1919-1920, Mr. Staley served as President of the AMERICAN CERAMIC SOCIETY, and was Editor of the *Journal of the American Ceramic Society* in 1920, and until the latter part of 1922 served on the Committee on Publications. Mr. Staley was also editor of the *Transactions of the American Ceramic Society* for 1914 and 1915. He has contributed many articles on ceramic technology to various journals. He is also a member of the Committee on molding sand of the National Research Council.



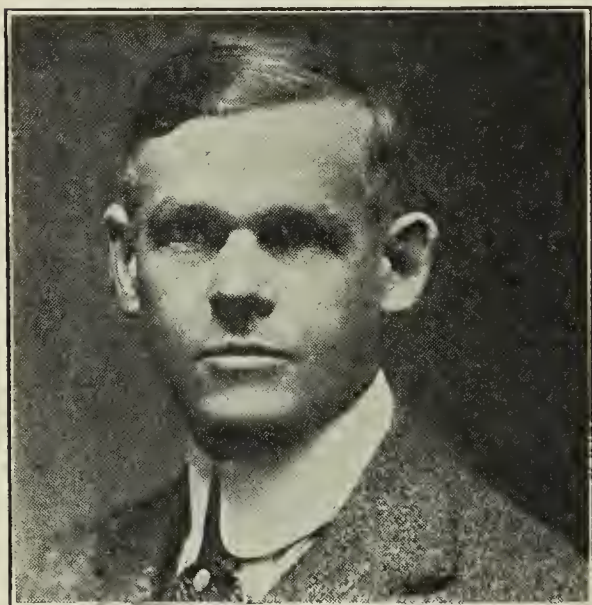
HOMER F. STALEY

Ohio State University, and Supervising Ceramist for the Bureau of Mines.

Mr. Stull was Vice-President of the AMERICAN CERAMIC SOCIETY in 1915-1916, and was President of the SOCIETY 1918-1919. He is also affiliated with Sigma Xi, and is an Honorary Member of the Illinois Clay Workers' Association.

LeRoy Himes Minton

LeRoy H. Minton was born in Covington, Ohio, in 1882, descendant of the Minton family of potters in England. During his college course in vacations he worked at his trade as a brick layer. He was graduated from the Ohio State University in 1904 with the degree of M.E. in ceramics. Following his graduation he was employed as Ceramic Chemist in a refractory works and

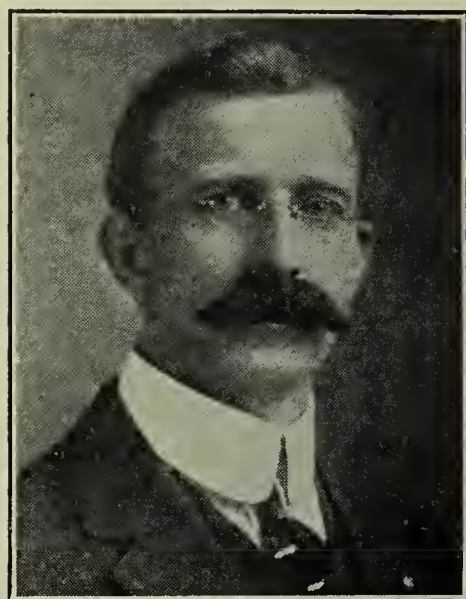


L. R. H. MINTON

the SOCIETY as well as to other technical papers. He is also President of the New Jersey Clay Workers' Association and Eastern Section of the AMERICAN CERAMIC SOCIETY.

Ray T. Stull

Mr. Stull was born at Elkland, Pa., in 1875, and was graduated from Ohio State University in 1902. From 1902-1904 he was a chemist with the American Terra Cotta & Ceramic Co.; from 1905-1907, Superintendent of Mt. Savage Enamelled Brick Works; from 1907-1909, Superintendent of Steiger Terra Cotta & Pottery Co., San Francisco, California; and Instructor in Ceramics, University of Illinois; Associate in Ceramics, University of Illinois, 1909-1910; Assistant Professor, 1910-1915; Ceramic Engineer, Dunn Wire Cut Lug Co., 1915-1917, and from 1917-1922 was Superintendent of the Ceramic Experiment Station, Bureau of Mines,



RAY T. STULL

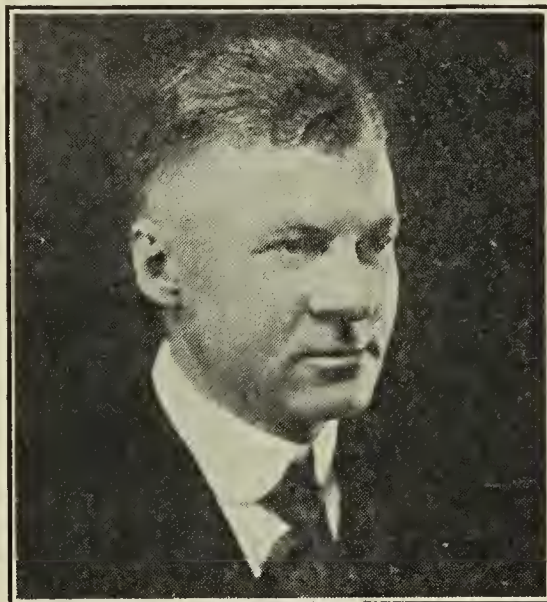
later became Chemist at the Mosaic Tile Company at Zanesville, Ohio. In the fall of 1906 he became Ceramic Chemist for the Perth Amboy Terra Cotta Company at Perth Amboy, N. J., and in 1913 he became Superintendent of the Wilkes-Barre Terra Cotta Company. In 1914, Mr. Minton went to Metuchen, N. J., where he became Superintendent of Plant No. 2, of the General Ceramics Company, and was made General Superintendent of this same Company in 1921.

Mr. Minton is an active member of the AMERICAN CERAMIC SOCIETY. He served as President of the SOCIETY during 1920-1921 and has been a member of the Committee on Publications for the *Journal* for the past two years. Mr. Minton has contributed to the *Journal* of

Forrest Kizer Pence

Forrest K. Pence of Zanesville, Ohio, was born in Sidney, Ohio, in 1883. His B.S. degree was received in 1903 from Ohio Northern University, his A.B. from the Ohio State University in 1907, and the degree of Ceramic Engineer from the latter University in 1909. From 1909 to 1912, Mr. Pence was Ceramic Engineer with the American Encaustic Tiling Company. For one year, Mr. Pence was Professor of Ceramic Engineering at Ohio State University, after which he returned to Zanesville to become Ceramic Engineer and Superintendent of Manufacture with the American Encaustic Tiling Company. He accepted the position of Research Ceramist with Knowles, Taylor and Knowles in the Spring of 1922.

Mr. Pence served as Vice-President of the AMERICAN CERAMIC SOCIETY during 1916-1917, and as President in 1921-1922. He is also a member of the American Chemical Society.

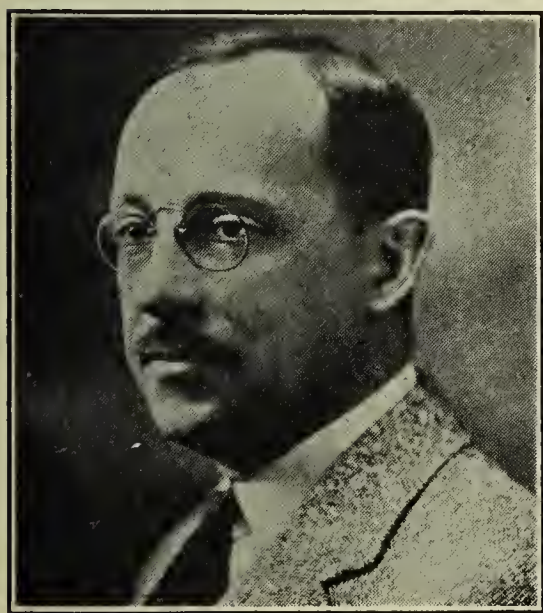


FORREST K. PENCE

Frank H. Riddle

Frank H. Riddle was born in Colorado Springs, Colorado in 1883. He has been connected with the ceramic industry since 1902, starting in the Van Briggles Art Pottery at Colorado Springs. From 1904 until 1907 Mr. Riddle took a special course in ceramic engineering at Ohio State University and was also part time instructor in the ceramic laboratory. After leaving school he became manager of the Van Briggles Pottery for three years. From 1910 to 1916 he engaged in work in heavy clay products plants in Ohio, British Columbia, and California. This work included construction and plant operation in sewer pipe and face and fire brick. He was then employed in the Clay Products Division of the United States Bureau of Standards at Pittsburgh from 1916

to 1919, as assistant to A. V. Bleining in research work in special porcelains, including spark plug, also refractories for optical glass manufacture. Since 1919, he has been with the Champion Porcelain Company of Detroit, a branch of the Champion Spark Plug Company, and associated with Dr. J. A. Jeffery in research and plant control work for spark plugs and high tension insulators.



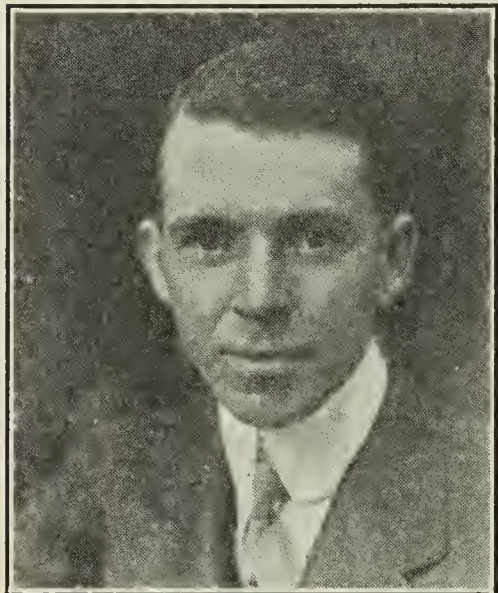
FRANK H. RIDDLE

Mr. Riddle is President of the AMERICAN CERAMIC SOCIETY at the present time. He has worked on Committees on Rules, Standards and Membership. He was Secretary of the Pittsburgh District Section and for three years served as a member of the Board of Trustees. Mr. Riddle has published several articles in the *Journal of the American Ceramic Society*.

Arthur F. Greaves-Walker

A. F. Greaves-Walker received his technical education in ceramics at the Ohio State University, completing his course in 1904. He has held the following positions:

Chemist and Mining Engineer, Olive Hill Fire Brick Company, Olive Hill, Kentucky, 1905-1906; Superintendent, Utah Fire Clay Company, Salt Lake City, Utah, 1907-1910; Superintendent, Southern Clay Manufacturing Company, Coaldale, Alabama, 1911-1912; Assistant General Manager of the Sun Brick Company, Toronto, Ontario, 1913-1916. From 1917 to the present time, he has



A. F. GREAVES-WALKER

been Production Manager of the American Refractories Company of Pittsburgh.

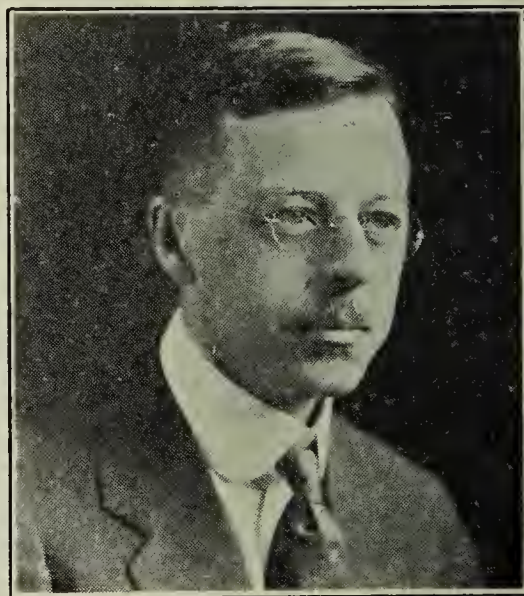
During the World War, Mr. Greaves-Walker served as a volunteer and was appointed Chief of the Industrial Furnace Section of the United States Fuel Administration at Washington. This Section had jurisdiction over the entire ceramic, as well as all other non-metallic industries of this country during the War. As an author, Mr. Greaves-Walker has contributed liberally to the scientific and technological world, having seven contributions published in the *Transactions of the American Ceramic Society*.

Mr. Greaves-Walker is an active member of the AMERICAN CERAMIC SOCIETY, was Vice-President in 1918, Chairman of the Refractories Division in 1921, and Chairman of the Pittsburgh Section of the SOCIETY, 1922-1923. He also was appointed to fill out the unexpired term of Homer F. Staley on the Committee on Publications. Other organizations of which Mr. Greaves-Walker is a member are the American Electro-Chemical Society, Committee C-8 of the American Society of Testing Materials, English Ceramic Society, Royal Society of Arts, Fellow Utah Academy of Sciences, and the Canadian National Clay Products Association, of which latter association he was President in 1915.

Ralph Kent Hursh

Ralph K. Hursh was born in Woodstock, Illinois, in 1885. During 1903 and 1904 he attended school at Western Illinois State Teachers' College, following which he attended the University of Illinois. He was graduated from the University of Illinois in 1908 with the degree of B.S. During 1909, he was stock and shipping clerk for the Ohio Mining and Manufacturing Company, and from 1909 to 1911, was junior ceramic chemist at the Bureau of Standards. Since 1911, Professor Hursh has been teaching in the Department of Ceramic Engineering at the University of Illinois.

Professor Hursh is an active member of the AMERICAN CERAMIC SOCIETY and, since 1917, has been Treasurer of the SOCIETY. He is also a member of the American Chemical Society. In his work in Ceramic Engineering, Professor Hursh is known chiefly for his research in drying and burning of clay wares and molding clay products.



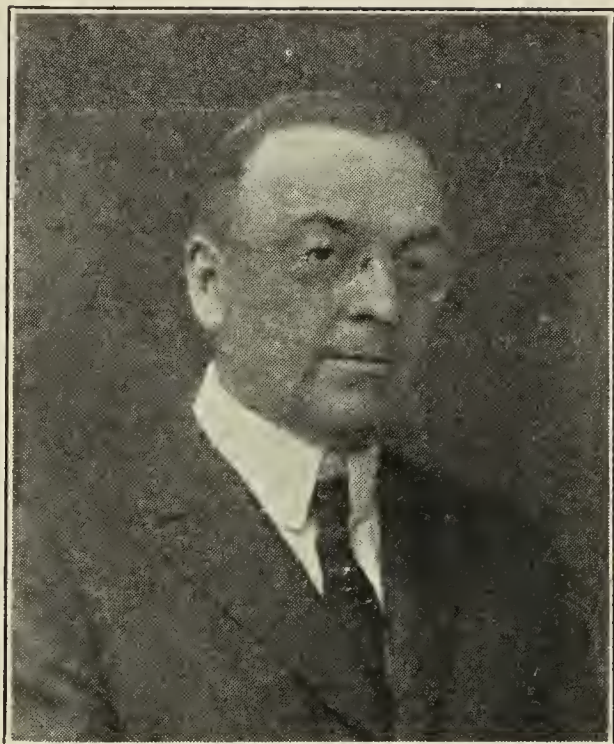
RALPH K. HURSH

Bert Eugene Salisbury

B. E. Salisbury was born in 1870 at Geddes, New York. He attended Cazenovia Seminary and 1890 entered the chemical laboratory of the Solvay Process Company.

In 1891 he associated himself with Pass & Seymour of Solvay, New York which firm was later incorporated. From the death of Mr. Pass in 1913 Mr. Salisbury was elected President of the Corporation which position he now holds. He also succeeded Mr. Pass as President of the Onondaga Pottery Company, Syracuse, New York.

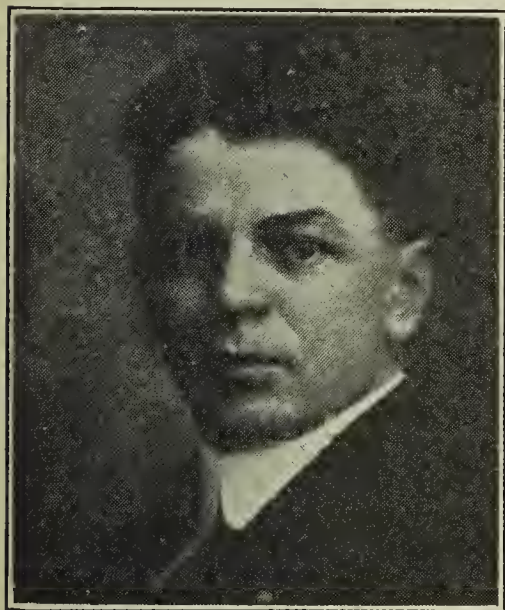
Mr. Salisbury is an active member of the AMERICAN CERAMIC SOCIETY and is a Trustee of the SOCIETY. He is also a Past President and now a Vice-President of the United States Potters' Association. During the World War, Mr. Salisbury was Chairman of the Clay Division of the War Industry Board of the Syracuse District.



B. E. SALISBURY

B. T. Sweely

B. T. Sweely was graduated from Iowa State College Ceramics in 1917. After leaving school



B. T. SWEELY

he was with the What Cheer Clay Products Company in Iowa for six months, after which he went to Chicago with the Western Electric Company of Chicago, Ill., Hawthorne Works. In 1920 he became Ceramist and Enameling Superintendent with the Coonley Mfg. Company where he remained until October, 1922, when he accepted a position with the Cribben & Sexton Company of Chicago.

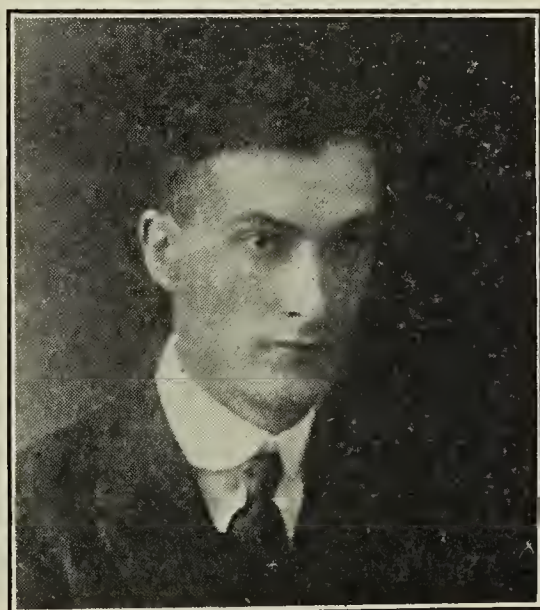
Mr. Sweely is an active member of the AMERICAN CERAMIC SOCIETY and is Chairman of the Enamel Division of the SOCIETY, 1922-1923.

Raymond Miller Howe

Raymond M. Howe was born in Elmira, New York, in 1894. His B.S. degree was received in 1915 from the New York State School of Clay Working and Ceramics

at Alfred, New York. During 1915-1916, he was Fellow at the University of Pittsburgh, and received his A.M. degree in 1916. For one year, he was instructor in chemistry at the latter University, and since 1917, has been Fellow at Mellon Institute, in Pittsburgh.

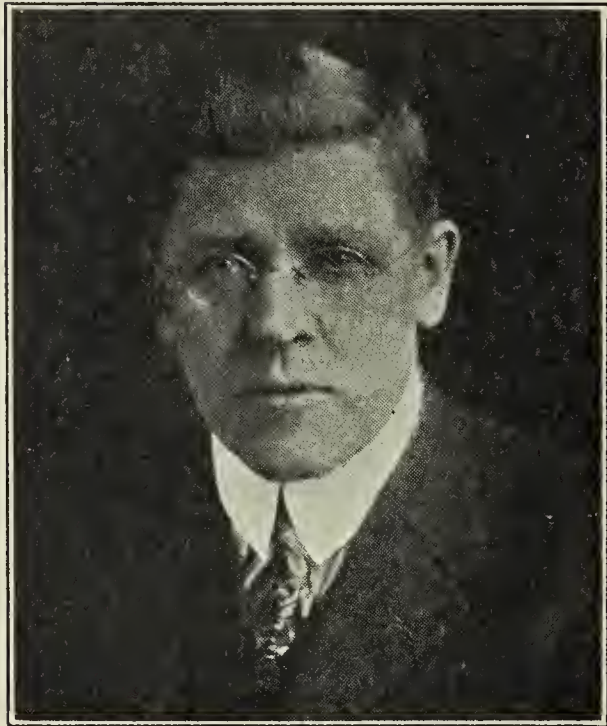
Mr. Howe has contributed many articles to the *Journal of the American Ceramic Society*, and was Secretary of the Refractories Division of the SOCIETY in 1919. For the past two years, he has been a member of the Board of Trustees of the SOCIETY. He is also a member of the American Chemical Society and the American Society for Testing Materials, and during 1918, served on the Advisory Committee of the War Industries Board.



RAYMOND M. HOWE

Adolph F. Hottinger

Adolph F. Hottinger was born in Chicago, 1872, and has lived in that city all of his life. He attended the public schools until the age of eighteen when he entered the terra cotta business as an apprentice. He thus gained a practical experience in all departments. With the exception of about six months which were spent in a machine shop at machine design, he has been connected with the terra cotta business all of his life. After four years spent in the laboratory of a terra cotta company, he took a course in Chemistry in a private laboratory and was subsequently made ceramist in charge of the Northwestern Terra Cotta Company. This position he retained until 1916 when he was made factory manager of the same firm. He still occupies this position and is also treasurer of the same firm.



A. F. HOTTINGER

Mr. Hottinger is an active member of the AMERICAN CERAMIC SOCIETY and during the past year has served as Chariman of the Terra Cotta Division of the SOCIETY. Mr. Hottinger was Vice-President of the SOCIETY during 1913-1914 and trustee 1902-1905 and 1916-1919.

Edwin Ward Tillotson

E. Ward Tillotson was born at Farmington, Connecticut, in 1884. He was graduated from Yale University in 1909 following which he was Resident Fellow, Department of Research, at the University of Kansas. In 1913, Dr. Tillotson was made Assistant Director of Mellon Institute of Industrial Research, Pittsburgh, which position he still holds.

Dr. Tillotson is the author of many papers on the chemistry of glass which have appeared in various scientific journals and technologic magazines. He is Vice-President of the AMERICAN CERAMIC SOCIETY (1922-1923), served as Secretary of the Glass Division from 1919 to 1922 and since 1919 has been a member of the Committee on Publications. He is the SOCIETY Representative on Committee D-10, American Society for Testing Materials. Dr. Tillotson is also Councilor of the American Chemical Society.



E. W. TILLOTSON

Herford Hope

Herford Hope was born in London in 1883, came to the United States in 1898, and was apprenticed to the Mayer Pottery of Beaver Falls, Pennsylvania. He became foreman of the Mayer Pottery in 1904, and in 1906 took a position as superintendent of the Huntington China Company, Huntington, West Virginia. In 1907, Mr. Hope became instructor in Ceramics at the University of Illinois. In 1908, he returned to the Mayer Pottery as Assistant Manager of that Company.

Mr. Hope joined the United States Naval Reserve Force in 1917, and was made a commissioned ensign in 1918. In 1919, he returned to the Mayer Pottery, and in 1921, went to England as manager of the Colne Brick and Terra Cotta Company, Essex County. At the present time, he is operating an art pottery near Newton Abbott, Devon.

Mr. Hope is an active member of the AMERICAN CERAMIC SOCIETY, and from 1913 to 1917 was Treasurer of the SOCIETY.



HERFORD HOPE

Harrison Everett Ashley¹

Harrison E. Ashley was born at New Bedford, Mass., in 1876 and obtained his collegiate training at the Massachusetts Institute of Technology from which he was graduated in 1900 with the degree of S.B. in Chemistry. Mr. Ashley specialized in metallurgy and after leaving school he took up the technology of foundry metal and



HARRISON E. ASHLEY

steel, holding several positions in steel plants and foundries. He later entered the employ of the Homer-Laughlin China Company at East Liverpool, Ohio, and in 1908 entered Ohio State University, taking a special course of six months under Professor Orton. He was later transferred by the Homer-Laughlin China Company to their plant at Newell, West Virginia, upon the completion of that plant. In 1908, Mr. Ashley was appointed Assistant Ceramic Chemist with the Technologic Branch of the United States Geological Survey and in 1910 was transferred to the Bureau of Standards which position he held until his death.

Mr. Ashley was an active member of the AMERICAN CERAMIC SOCIETY and from 1909 until

his death he served as Trustee of the SOCIETY. Mr. Ashley was a liberal contributor to technical literature.

Robert Dallas Landrum

Robert D. Landrum of Cleveland, Ohio, was born at Terre Haute, Indiana, in 1882. He received his degree of B.S. in 1904, and of M.S. in 1909 from the Rose Polytechnic Institute at Terre Haute, and in 1914, he took the degree of Chemical Engineer from the same institution. From 1904-1907, Mr. Landrum was chemist and enameler with the Columbian Enameling & Stamping Company of Terre Haute, and from 1907-1910 was Professor of Chemistry at the University of Kansas. He also held positions of



ROBERT D. LANDRUM

¹ Died February, 1911.

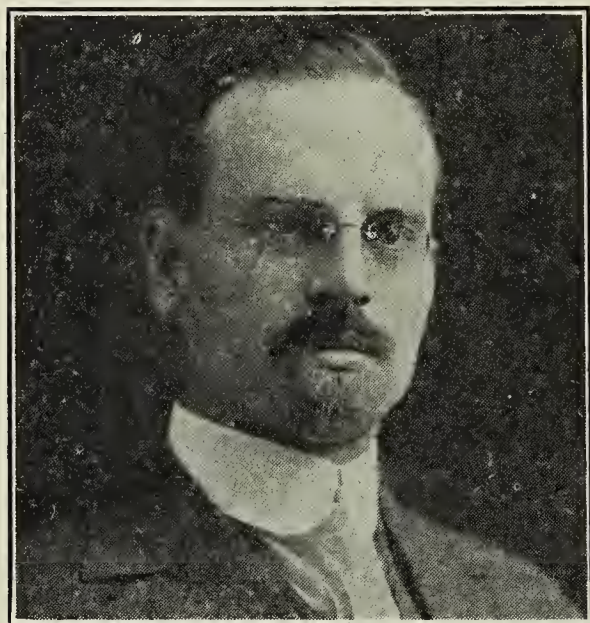
engineer with the Like Manufacturing Company of Canandaigua, New York, the Michigan Enameling Company of Kalamazoo, Michigan, and the General Stamping Company of Canton, Ohio. From 1914–1922, he was chemical engineer and manager of the Service Department of the Harshaw, Fuller and Goodwin Company of Cleveland, Ohio, and in 1922 was made vice-president of the Vitreous Enameling Company and Vitreous Steel Products Company of Cleveland, Ohio.

Mr. Landrum is the author of sixteen articles and technical papers in publications of this SOCIETY connected with the materials, methods and chemical analysis of enamel and enamel raw materials, and various processes in enameling

Mr. Landrum is an active member of the AMERICAN CERAMIC SOCIETY, and from 1918 to 1920, served as a trustee of the SOCIETY, and for the past two years, has been Chairman of the Committee on Papers and Program for the Annual Meeting of the SOCIETY. He was Chairman of the Enamel Division of the SOCIETY in 1920–1921 and Chairman of the Northern Ohio Section in 1921–1922. Other societies to which Mr. Landrum has allied himself are the American Chemical Society (Cleveland Section), America Institute of Chemical Engineers, the Cleveland Engineering Society, the Society of Chemical Industry (London), fellow of the A. A. A. S., and Société de Chimie Industrielle, Paris.

Edward Wight Washburn

Edward W. Washburn was born in Beatrice, Nebraska, in 1881. From 1899 to 1891, he was chemist at the University of Nebraska. In 1905, Dr. Washburn received his B.S. degree from the Massachusetts Institute of Technology, and his Ph.D. degree in 1908 from the same institution. He was Research Associate Chemist for two years at the Massachusetts Institute of Technology. From 1908 until 1910, he was Associate at the University of Illinois, Assistant Professor from 1910 to 1913, and Professor



E. W. WASHBURN

of Physical Chemistry from 1912 to 1916. In 1916, Dr. Washburn was appointed Professor of Ceramic Chemistry and head of the Department of Ceramic Engineering, where he was located until 1922, when he removed to Washington, D. C., as editor of the Annual Critical Tables of Physical, Chemical and Engineering Constants.

Dr. Washburn is an active member of the AMERICAN CERAMIC SOCIETY, and served as Editor of this *Journal* during 1921, and part of 1922.

Dr. Washburn is a member of the National Research Council, and during 1918–1919, was Acting Chairman of the Chemical Division of the Council. In 1919, he was delegate to the International Chemical Union and International Research Council in London and Brussels, and in 1921, was American Commissioner on the Inter-

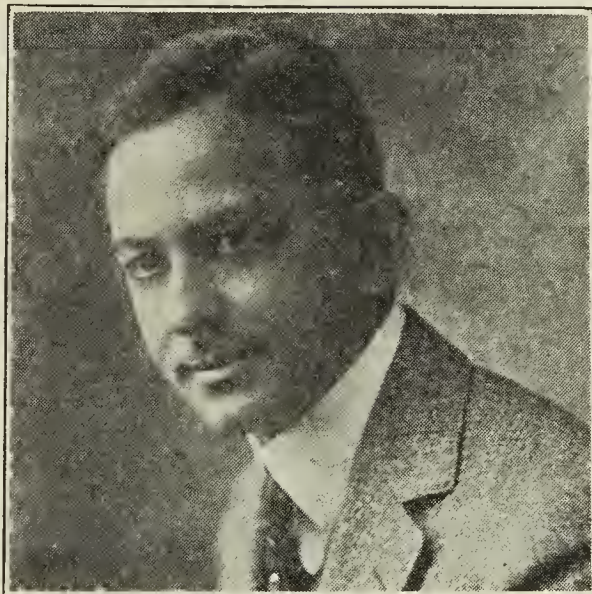
national Commission of Annual Tables of Physical and Chemical Constants. Other organizations of which he is a member are the American Chemical Society, Physical Society, Society of Glass Technology, Illinois Academy, and Royal Society of Arts.

Fred B. Ortman

Fred B. Ortman was born at New Salem, Ohio, in 1888. He was graduated from the Ohio State University in 1911 with a degree of Ceramic Engineer. During 1909–1910

he worked with the Alton Brick Company, Alton, Illinois as laborer, kiln burner and foreman. From 1911 until 1917 Mr. Ortman worked as Assistant Ceramist, Chief Ceramist, Assistant General Manager and Sales Manager for the New York Architectural Terra Cotta Company, Long Island City, New York. He was Chief Ceramist with the Northwestern Terra Cotta Company of Chicago from 1917 until 1920 and since that time has been Vice-President and General Manager of the Tropico Potteries, Inc., Glendale, California.

Mr. Ortman is an active member of the AMERICAN CERAMIC SOCIETY and served as Vice-President of the SOCIETY during 1921 and as trustee during 1922 filling out the unexpired term of Mr. Riddle. During 1918-1919 he was Chairman of the Terra Cotta Division and in 1919 was Secretary of the Chicago Division of the SOCIETY. Mr. Ortman is a member of the Board of Trustees at the present time.



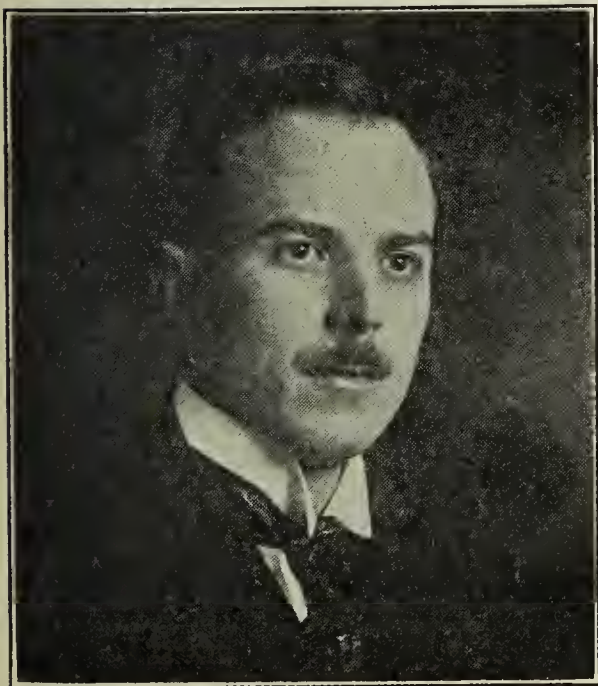
FRED B. ORTMAN

Earl T. Montgomery

Earl T. Montgomery received his degree of Engineer of Mines in Ceramics in 1907, and spent the two years following his graduation as Superintendent of the Wirt Manufacturing Company at Burrage, Massachusetts. He also spent a year in the engineering department of the Kinnear Manufacturing Company, at Columbus, Ohio. During 1910-1911, Mr. Montgomery was instructor in Ceramic Engineering at the University of Illinois, and for two years, was Assistant Ceramic Chemist with the United States Bureau of Standards, Pittsburgh Laboratory. From 1913-1916, he was Professor of Ceramic Engineering at the New York State School of Ceramics, Alfred, New York, leaving Alfred in 1916 for Detroit, where he was Director of Research with the Jeffery-

Dewitt Company (now the Champion Porcelain Company). Since 1919, Mr. Montgomery has been President and Manager of the Montgomery Porcelain Products Company of Franklin, Ohio.

Mr. Montgomery is an active member of the AMERICAN CERAMIC SOCIETY, and served as trustee from 1917 to 1919. In 1920 he was elected Vice-President of the SOCIETY. He is the author of several technologic papers published by the Bureau of Standards and in the publications of the AMERICAN CERAMIC SOCIETY.

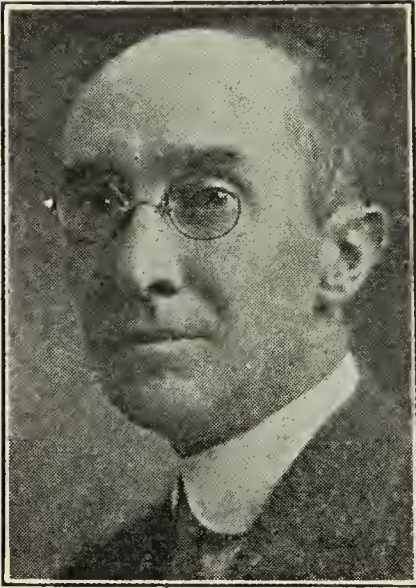


EARL T. MONTGOMERY

Harold Phelps Humphrey

H. P. Humphrey was born in 1881 at Osceola, Pa., and received his E.M. degree in ceramics from Ohio State University in 1904. The year following his graduation he was connected with the Cook Pottery Company at

Trenton, N. J., in 1906 and 1907 he was ceramist with the Northeastern Terra Cotta Company at Bradford, Pa., and in 1908 was Assistant Superintendent of the plant of

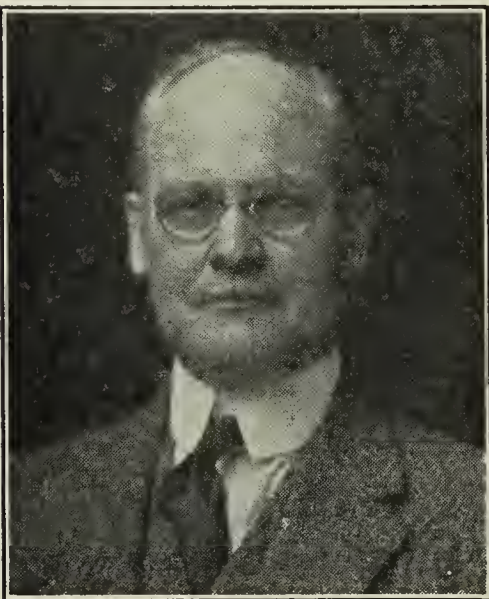


H. P. HUMPHREY

the Cook Pottery Company at Ford City, Pa. For six years, from 1909 to 1914 Mr. Humphrey was Superintendent of the Prospect Hill Works of the Cook Pottery and until 1917 was Vice-President and general manager of the same firm. In 1918 he became Vice-President and general manager of the Washington Porcelain Company at Washington, New Jersey, which position he still retains.

Mr. Humphrey is an active member of the AMERICAN CERAMIC SOCIETY and served as trustee for the SOCIETY from 1912 to 1915.

panies of Pennsylvania, 1904-1906, and from 1906 to 1914, Manager of the Denny Renton Clay and Coal Company of Seattle, Washington. For two years following, Mr. Farnham was supervising engineer of the Emerson Company. He established a consulting practice in St. Louis, Missouri, and during the War, from 1916 to 1920, did special work for the Emergency Fleet Corporation and Ordnance Department. He subsequently did consulting industrial engineering work for the Evens and Howard plants, and for the LaCled-Christy Plants in St. Louis, Missouri. During 1920, Mr. Farnham studied industrial conditions in France, Italy, Germany and England, and in 1921, became Vice-President and Director of the C. E. Knoeppel & Co., Inc., in New York City. In 1922, Mr. Farnham, with Irving A. Berndt, opened offices for consulting practice in New York City.



WM. J. CANNAN

brick and heavy clay ware. He also served six months in the Navy during the Spanish American War. Following the War he took a short course of two and one-half years

the Cook Pottery Company at Ford City, Pa. For six years, from 1909 to 1914 Mr. Humphrey was Superintendent of the Prospect Hill Works of the Cook Pottery and until 1917 was Vice-President and general manager of the same firm. In 1918 he became Vice-President and general manager of the Washington Porcelain Company at Washington, New Jersey, which position he still retains.

Mr. Humphrey is an active member of the AMERICAN CERAMIC SOCIETY and served as trustee for the SOCIETY from 1912 to 1915.

Dwight Thompson Farnham

Dwight T. Farnham was born at Candor, New York, in 1881. He was graduated from Yale with the degree of A.B. in 1904. His first positions in the ceramic industry were with the Clermont and Shamut Manufacturing Com-



DWIGHT T. FARNHAM

Mr. Farnham is an active member of the AMERICAN CERAMIC SOCIETY, and during 1914-1915 was Vice-President of the SOCIETY.

He is Vice-President and Director of the Society of Industrial Engineers, a member of the American Society of Mechanical Engineers, Yale Engineering Society, and the National Personnel Association. He has contributed to the *Journal of the American Ceramic Society*, and also to other journals and magazines, his subjects in general dealing with industrial efficiency and control.

W. J. Cannan

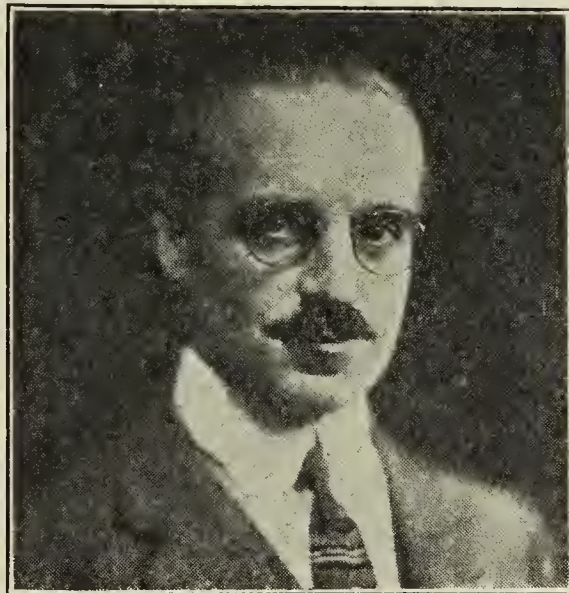
W. J. Cannan was born in 1875 and at the age of fifteen was working for the E. M. Freese Manufacturing Company of Gallion, Ohio. Of the thirty-three intervening years he spent six years in the manufacture of clay machinery, and two in the manufacture of paving

at the Ohio State University. Fifteen out of eighteen years since completing this short course he has spent in the Onondaga Pottery Company of Syracuse, New York, where he is now General Superintendent.

Mr. Cannan is an active member of the AMERICAN CERAMIC SOCIETY and served as trustee of the SOCIETY from 1910 until 1913.

Frederick H. Rhead

Frederick H. Rhead was born at Hanley, Staffordshire, in 1880. He comes of a family of artists and potters for several generations. He was apprenticed at Brownfields of Cobridge in 1893, having attended local art schools before that time. For three years previous to coming to this country he was instructor in Government Art School at Longton. During this time he was also a special artist at Foresters Art Pottery in Longton. Two years were spent with his father during the building and organizing of the art pottery for Wileman & Company, Longton, and two years more as Art Director of Wardle Pottery of Hanley. After coming to the United States Mr. Rhead was Art Director of the Roseville Potteries, Zanesville, Ohio for six years and for five years was President and General Manager of the Rhead Pottery of Santa Barbara, California. His work received gold medals at the St. Louis Exposition as well as the World's Fair Exposition at San Diego, California. For the past four years Mr. Rhead has been Director of Research and Active Head of the Art Department of the American Encaustic Tiling Company, Zanesville, Ohio, Maurer, N. J., Los Angeles, California and New York City. Mr. Rhead has contributed to numerous art journals, articles in Research



FREDERICK H. RHEAD

Reports on ceramic processes and designing and has lectured widely on his subject. He has also exhibited his work frequently.

Mr. Rhead is an active member of the AMERICAN CERAMIC SOCIETY and is Chairman of the Art Division, having organized that Division of the SOCIETY. He is also a member of the English Ceramic Society, English Chemists' Club and the Architectural League of New York City.

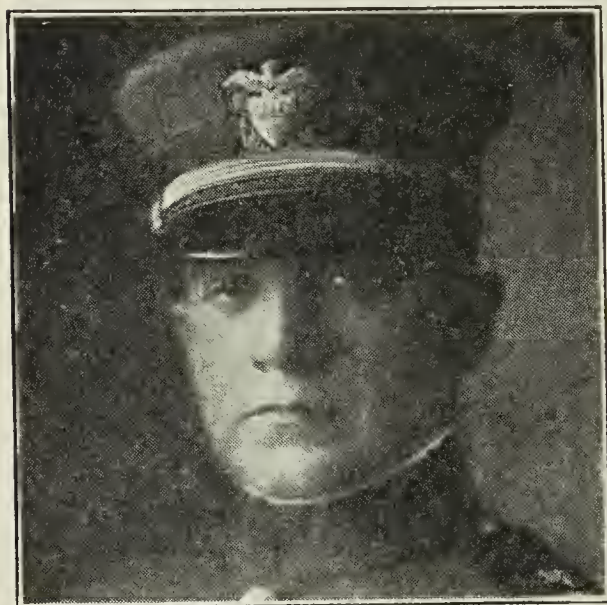


MABEL C. FARREN

Mabel C. Farren

Miss Mabel C. Farren was a student for four years in the Allegheny School of Art and the Art Students' League under the direction of Martin Borgord, specializing in drawing and painting. She also spent two years modeling with August Zeller at the Carnegie Institute, and two years were also spent in studying Interior Decoration at the School of Fine Arts, Carnegie Institute. Miss Farren won the medal of the First Class, Duquesne Ceramic Club for Ceramic Design and Decoration in 1902 and in 1903 she won medals of the same organization for Second and Third Class. In 1911 she was honored with the medal of the third class by the Society of Beaux Arts.

From 1900 until 1908 Miss Farren conducted a private studio and for two years following was instructor in Pottery and Design in the Art Students' League of Pittsburgh. For five years, from 1910 until 1915, she served as instructor of design and ceramics at the Carnegie Institute of Technology. During the summer of 1911 she studied with Frederick H. Rhead at the St. Louis School of Ceramics.



Miss Farren was the first woman member of the AMERICAN CERAMIC SOCIETY and for two years served as Secretary of the Art Division of the SOCIETY. She is also a member of the Art Alliance of America and the Art Society of Pittsburgh.

Herbert L. Kirk

Herbert L. Kirk was born in 1895 at New Castle, Pa. The year 1914-1915 he spent working in a pottery laboratory in New Castle and from 1915 until 1917 he studied chemical engineering and business administration at Lehigh University. From 1917 until 1919 he was a member of the United States Naval Reserve Force and saw service in France. After his discharge from service he became associated with the Universal Sanitary Manufacturing Company, of New Castle, Pa., which position he retains as Sales Manager and Research Engineer.

Mr. Kirk is an active member of the AMERICAN CERAMIC SOCIETY and is now serving as Secretary of the Art Division of the SOCIETY.

Ralph R. Danielson

R. R. Danielson was born in Chicago, Ill., in 1892, and was graduated from Crane Technical School in 1910. In 1914, he was graduated from the University of Illinois with degree of B.S. in Ceramic Engineering, and took a post-graduate course, securing the degree of M.S. in Ceramic Engineering in 1916.

From 1914-1916 he was instructor in Ceramic Engineering, University of Illinois; from 1916-1919, Ceramic Engineer, Royal Enameling Co. and Benjamin Electric Co., Desplaines, Illinois; from 1919-1920, Enamel Technologist, U. S. Bureau of Standards, Washington, D. C., and since 1920 has been Chief of the Enameled Metals Section, U. S. Bureau of Standards.

Mr. Danielson is an active member of the AMERICAN CERAMIC SOCIETY, and is now Secretary of the Enamel Division. He has contributed numerous papers to the *Journal of the American Ceramic Society*.



R. R. DANIELSON

Charles Edwin Jackson

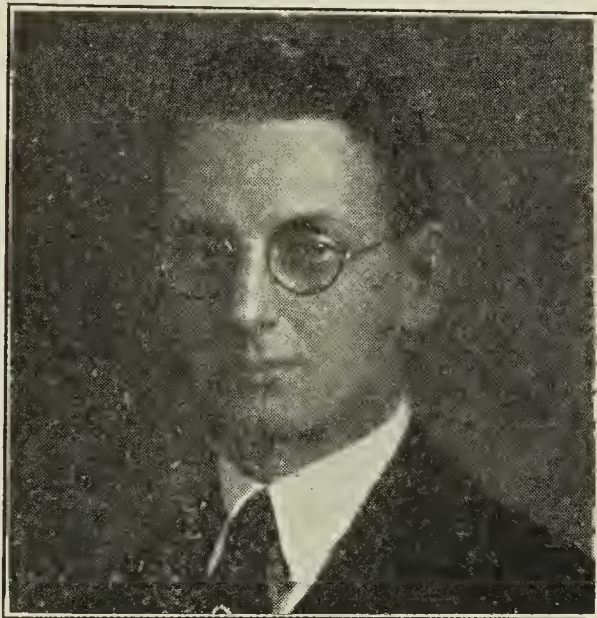
C. E. Jackson was born in 1874 at Hanley, Staffordshire, England, and emigrated to this country in 1882. His family for many generations has been connected with pottery manufacture. He left school when he was fourteen years of age and was employed by the Wheeling Pottery Company as an apprenticed mould maker, later taking up other

work in the factory. At the age of twenty-five Mr. Jackson became a student of the ceramic department at Ohio State University, completing the short course in ceramics in 1902. For three years he was ceramic engineer for the Wheeling Pottery Company and from 1905 until 1910 he was ceramic engineer for the Onondaga Pottery Company, Syracuse, N. Y. On January 1, 1911, Mr. Jackson was elected president and general manager of the Warwick China Company of Wheeling, W. Va., where he is located at the present time.

Mr. Jackson is a member of the AMERICAN CERAMIC SOCIETY, of which he was Vice-President in 1917-18.

Emerson P. Poste

Emerson P. Poste was born in Naples, New York, in 1888. He received his degree of B.S. from the Department of Chemical Engineering, Carnegie Institute of Technology, Pittsburgh, Pa., in 1910. From 1910 to 1912, he was assistant instructor and research assistant to the head of the Department of Chemical Engineering, Carnegie Institute. From 1912 to 1916, Mr. Poste was chemist with the Enameled Pipe & Engineering Company of Elyria, Ohio, and from 1916 to the present date, he has been director of laboratories of the Elyria Enameled Products Company, Elyria, Ohio.



EMERSON P. POSTE

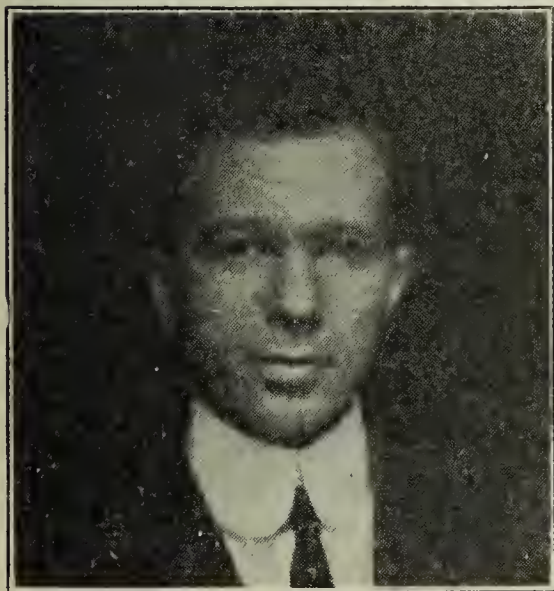
Mr. Poste is an active member of the AMERICAN CERAMIC SOCIETY. He was Chairman of the Northern Ohio Section of the SOCIETY from 1918-1920, as well as Chairman of the Enamel Division during 1920-1921. During 1922-1923, he has served on the Committee of Standards as a representative of the Enamel Division, and is a member of the Standing Committee on Membership.

Mr. Poste is also a member of the following technical organizations: American Chemical Society, American Institute of Chemical Engineers, American Association for the Advancement of Science, American Welding Society, Cleveland Engineering Society, English Society of Glass Technology.

Arthur E. Williams

Arthur E. Williams was born in Cleveland, Ohio, in 1886. He received his B.S. degree in ceramics at the University of Illinois in 1910 and his Master's Degree in ceramic engineering from the same University in 1916. During the year 1910-1911 he was superintendent of the Monmouth Brick and Tile Company at Monmouth, Illinois, and the following year was assistant to the foreman and kiln fireman for the Western Brick Company at Danville, Illinois. From November, 1913, until July, 1916, Mr. Williams was instructor in the Department of Ceramics at the University of Illinois, and since that time has been Ceramic Chemist for the Glass Section of the United States Bureau of Standards, at Washington, D. C.

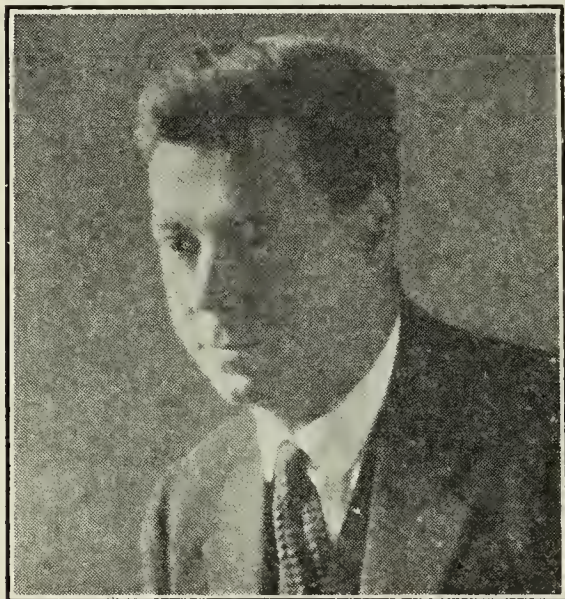
Mr. Williams is an active member of the AMERICAN CERAMIC SOCIETY and has been a frequent contributor to the *Journal* of the SOCIETY as well as to other technical publications. He is secretary of the Glass Division.



A. E. WILLIAMS

J. C. Hostetter

J. C. Hostetter was born in Williamsport, Pa., in 1886. After graduating in the chemical course from Bucknell University, he pursued graduate work there and at the University of Chicago. From 1908 until 1910 he was instructor in chemistry at Bucknell University and was assistant chemist at the Bureau of Standards from 1910 to 1912. Mr. Hostetter then became physical chemist at the geophysical laboratory, Carnegie



J. C. HOSTETTER

Institution of Washington. In 1919, he took up the manufacture of colored glassware at the Steuben Division of the Corning Glass Works and in 1920 was made manager of this Division. He is now Assistant to the Vice-President in Charge of Operations of the Corning Glass Works.

Mr. Hostetter is an active member of the AMERICAN CERAMIC SOCIETY, served as Vice-Chairman of the Glass Division for 1921-22 and Chairman for 1922-23. He is also a member of the American Chemical Society, Washington Academy of Sciences, Washington Philosophical Society, and Society of Glass Technology. Mr. Hostetter has contributed many articles to this *Journal* and other scientific publications.

M. B. Greenough

Mr. Greenough is Secretary of the Heavy Clay Products Division of the SOCIETY.

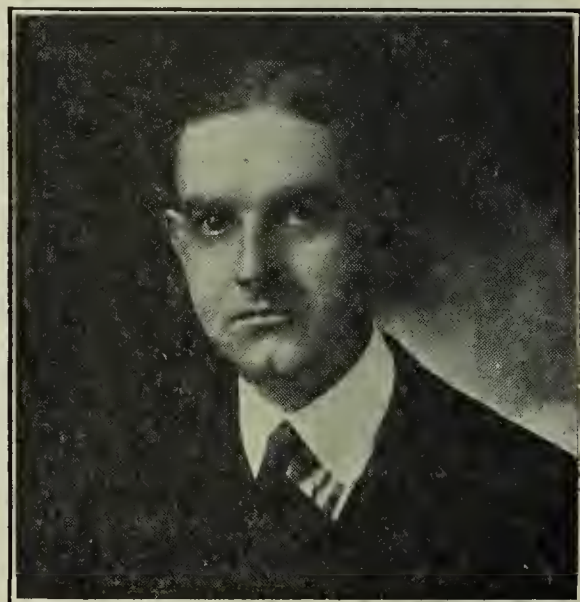
M. F. Beecher

M. F. Beecher was graduated from Iowa State College in 1910 with the B.S. degree and in 1915 received the degree of Ceramic Engineer from the same school. Following his graduation he was employed as yard foreman with the Boone Brick Tile & Paving Company, Boone, Iowa and later was assistant to the superintendent at plant No. 2 of the Western Stoneware Company of Monmouth, Illinois. In the latter part of 1911 Mr. Beecher returned to Ames, Iowa, to become assistant ceramic engineer at the Engineering Experiment Station. In 1915 he entered the employ of Norton Company, Worcester, Mass., to work on refractories in the research laboratories. He was put in charge of the ceramic section of this Company in 1916 and since 1919 has been research engineer, assuming general charge of the Laboratories at Worcester. Mr. Beecher has contributed articles on clay to the publications of the AMERICAN CERAMIC SOCIETY.

Mr. Beecher is an active member of the AMERICAN CERAMIC SOCIETY, serving one term as Trustee from 1919-1922 and from 1917-1922 was Chairman of the Committee on Standards.

C. Forrest Tefft

C. Forrest Tefft was graduated from the New York State School of Ceramics and Clay Working at Alfred, N. Y., in 1914. Previous to his graduation he had five years' experience in the roofing tile business with the Ludowici-Celadon plant, first in their plant at Alfred, N. Y., and later in the plant at Coffeyville, Kansas. During his senior year at college the New York State Student Branch of the American



MAURICE B. GREENOUGH

Ceramic Society was organized and Mr. Tefft was made its first President. Mr. Tefft is now Assistant Factory Manager for Fiske and Company, Inc., with headquarters at Watsonstown, Pa., where the main office of the Company is located.

Mr. Tefft is an active member of the AMERICAN CERAMIC SOCIETY and for the past year has been Chairman of the Heavy Clay Products Division of the SOCIETY.



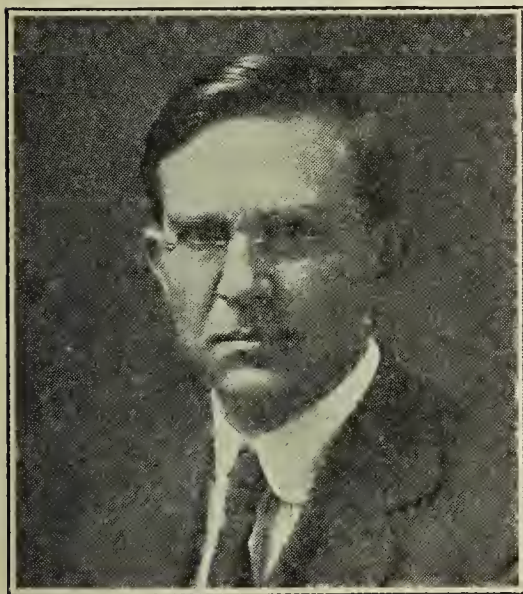
C. FORREST TEFFT

Frederick Addison Harvey

Frederick A. Harvey was born at Kellogg, Iowa, in 1882. He took his B.S. degree at Grinnell College in 1904 and during 1908-1909 worked under a Whiting Fellowship at the University of California and received his degree of Ph.D. in 1909. During

1909-10, Dr. Harvey was Instructor in physics at Grinnell and the following year held the same position at the University of Syracuse. In 1916, Dr. Harvey left this University where he was Associate Professor and became Physicist for the Semet-Solvay Company of Syracuse. Since 1921 Dr. Harvey has been connected with the United States Refractories Corporation at Mt. Union, Pa.

Dr. Harvey is an active member of the AMERICAN CERAMIC SOCIETY, is serving as Secretary of the Refractories Division and has contributed articles to the *Journal*. He is a member of the A. A., an associate of the Physical Society and of the American Chemical Society.



FRED A. HARVEY

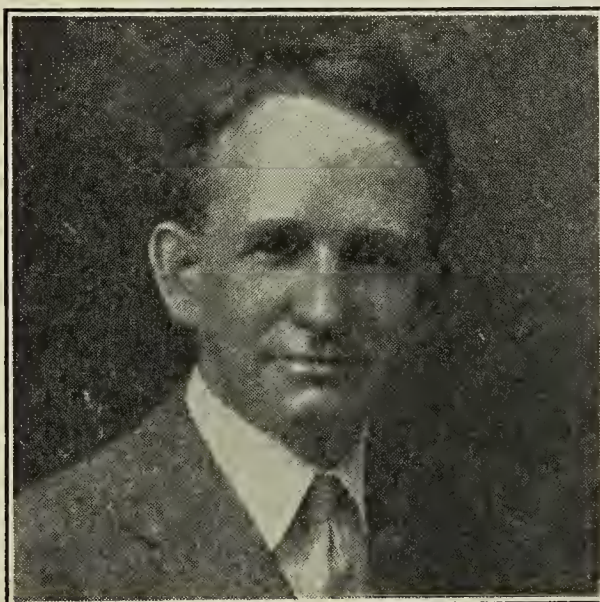
J. Spotts McDowell

J. Spotts McDowell is a graduate of the Massachusetts Institute of Technology where he received his B.S. degree. He is an active member of the AMERICAN CERAMIC SOCIETY and is Chairman of the Refractories Division. Other technical and scientific societies of which he is a member are the American Chemical Society, American Society for Testing Materials, American Electrochemical Society, American Institute of Mining and Metallurgical Engineers, Engineer's Society of Western Pennsylvania, Society of Glass Technology (British) and the Ceramic Society (English).

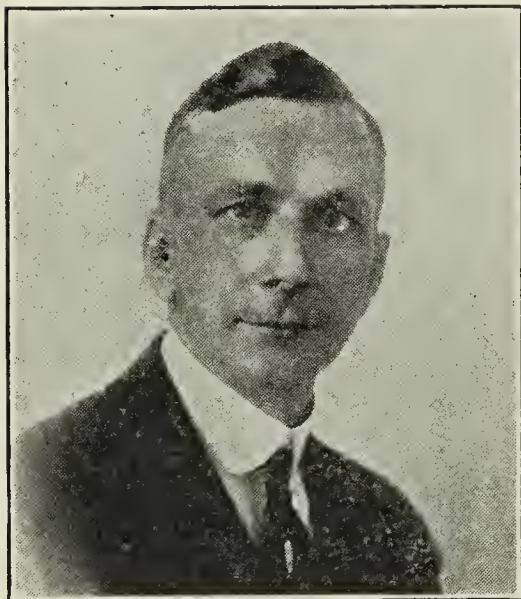
Robert L. Clare

Mr. Clare was graduated from the Ohio State University in 1912, with the degree of Ceramic Engineer. He worked with Professor Orton at the University and at his laboratory during the last year of his college course.

After graduation, he was connected with Richardson-Lovejoy Engineering Co. as engineer



J. SPOTTS McDOWELL



ROBERT L. CLARE

Illinois. The year following his graduation, he spent with the Kankakee Tile and Brick Company, and in 1917 he became ceramic engineer with the General Electric Company at Schenectady, New York, and was transferred recently by the same Company to Pittsfield, Massachusetts.

Mr. Treischel is an active member of the AMERICAN CERAMIC SOCIETY, and is Secretary of the White Wares Division. He has also contributed articles of ceramic interest to this *Journal*.

Le Roy W. Allison

Le Roy W. Allison was born in 1884 and received his education in Brooklyn, N. Y. He first took up electrical and mechanical engineering in New York and Los Angeles. In 1910 he took up technical and business



L. R. W. ALLISON

and draughtsman; with Macon, Dublin & Savannah Railroad as prospecting engineer to locate bauxite properties in southern Georgia; with Federal Terra Cotta Co. in 1913 as Ceramic Engineer, subsequently as Assistant Superintendent, and finally as Superintendent, which position he has held since 1916.

Mr. Clare is an active member of the AMERICAN CERAMIC SOCIETY, and is serving as Secretary of the Terra Cotta Division. He is also a member of the Technical Committee, National Terra Cotta Society.

Chester H. Treischel

Chester H. Treischel was born at Martinton, Illinois, in 1894. In 1916, he received his degree of B.S. in Ceramic Engineering at the University of



CHESTER H. TREISCHEL

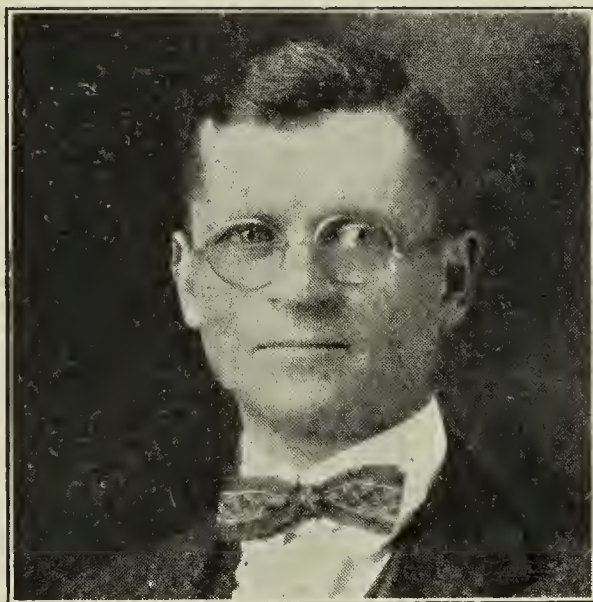
journalism, later returning to New York to continue his work with the technical press. Since 1917 he has devoted his entire time and efforts to technical journalism and engineering advertising. Mr. Allison became identified with the ceramic industry of New Jersey about five years ago. He is now editor of *The Ceramist*, a publication for the New Jersey Clay Workers' Association and Eastern Section of the AMERICAN CERAMIC SOCIETY. He has been advertising manager for the *Journal of the American Ceramic Society* since 1920. Mr. Allison is also a member of the A. A. S., associate member of the American Institute of Electrical Engineers and a fellow member of the American Geographical Society.

Joseph B. Shaw

J. B. Shaw was graduated from Ohio State University in 1908, and became superintendent of the enameling department of the Grand Rapids Refrigerator Company of Grand Rapids, Michigan. During 1911-1912, he did

ceramic research work with the Andrew Ramsey Company of Mount Savage and Ellerslie, Maryland, and from 1912 to 1915, conducted ceramic research in the Pittsburgh Testing Laboratory. From 1915 until the present time, Professor Shaw has been Assistant Director and Professor of Ceramic Engineering at the New York State School of Clay Working and Ceramics, Alfred, New York.

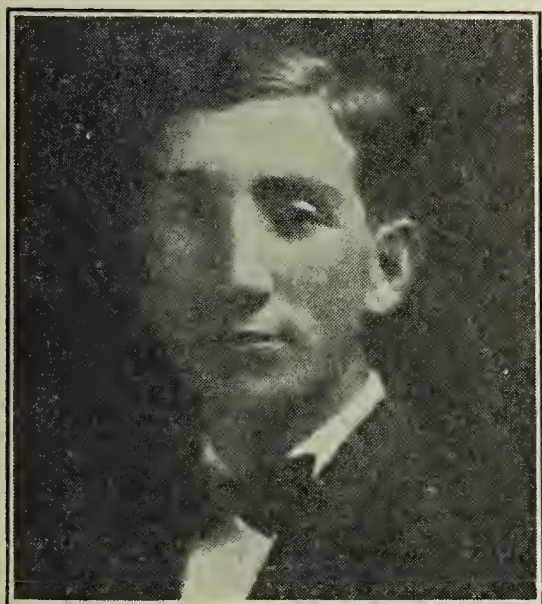
Professor Shaw is an active member of the AMERICAN CERAMIC SOCIETY, and has served on the Committees on Rules, Standards, and Sections and Divisions. During 1918-1922 Professor Shaw was treasurer of the New York State Section of the AMERICAN CERAMIC SOCIETY and is Councillor for the New York State Student Branch of the SOCIETY. At the present time, Prof. Shaw is the representative of the Enamel Division on the Committee on Rules. He has made numerous contributions to the publications of the AMERICAN CERAMIC SOCIETY, as well as to other technical and scientific publications.



PROF. J. B. SHAW

Charles H. Kerr

C. H. Kerr was born at Cleveland, Ohio, in 1884. He completed his ceramic course at Ohio State University in 1906, having received his degree of E.Min. in Cer. From 1907-1908, he was chemist for the Carborundum Co., Niagara Falls, N. Y., leaving that firm to pursue the same work with the American Optical Co., Southbridge, Mass. He then became Director of the Research Laboratory of the Pittsburgh Plate Glass Co., Pittsburgh, Pa., 1911-1917. In 1917, he accepted the position of Research Manager of the American Optical Co., Southbridge, Mass., which he held until 1920. At present he is connected with the De-Zeng Standard Co., Camden, N. J., being its Vice-President and Secretary.



CHARLES H. KERR

Mr. Kerr is an active member of the AMERICAN CERAMIC SOCIETY, having called the organization meeting of the Glass Division and being appointed its first Chairman. He is also a member of the American Chemical Society, Society of Glass Technology and a charter member of the Optical Society of America. At present he is Assistant Editor of *Chemical Abstracts*.

Walter A. Hull

Walter A. Hull was graduated from Ohio State University in 1902 with the degree of Engineer of Mines in Ceramics. He spent twelve years in industrial work, mainly in executive positions connected with the manufacture of refractories and other heavy clay products. For nearly nine years

past, he has been connected with the United States Bureau of Standards, working first on the study of fire-resistive properties of building materials, and more recently on ceramic problems.

He is a member of the AMERICAN CERAMIC SOCIETY, and for the past year has served as the Chairman of the Committee on Standards. He is also a member of the



WALTER A. HULL

In 1902, Mr. Clark studied at the Polytechnikum, Zürich, Switzerland and in 1903 he attended the University of Berlin and Charlottenburg Technical School. From 1904 until 1906 he was located in London, Eng., following which he returned to New York and took a position with the General Chemical Co. where he remained until 1911. Since 1911 he has been affiliated with glass interests of National Lamp Works of the General Electric Co. at Cleveland, Niles, Fostoria and Newark, Ohio, his present position being Manager of the Glass Technology Department located at Nela Park, Cleveland, Ohio.

Mr. Clark is an active member of the AMERICAN CERAMIC SOCIETY and is at present Chairman of the Committee on Research. He also served as Chairman of the Glass Division in 1921.

American Iron and Steel Institute, and American Society for Testing Materials. In connection with the latter organization, he is a member of the following committees: C-4 on Clay and Cement Sewer Pipe, C-8 on Refractories, C-11 on Gypsum, and D-9 on Electrical Insulating Materials. He is chairman of Committee C-10 on Hollow Building Tile of the A. S. T. M. Other committees on which Mr. Hull serves are the Executive Committee and Committee on Building Construction of the National Fire Protection Association.

William M. Clark

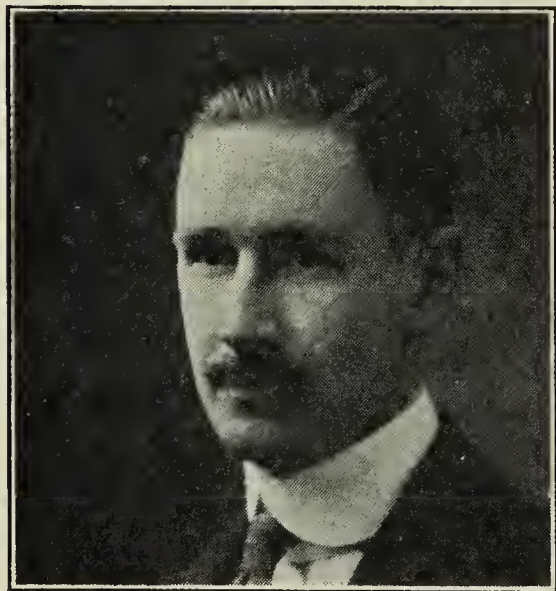
William M. Clark was born in Derby, Conn., in 1880. He was graduated from Sheffield Scientific School, Yale University, in 1901 and pursued his post-graduate work at the Mass. Institute of Technology.



WM. M. CLARK

O. O. Bowman, 2nd

O. O. Bowman, 2nd, entered Rutgers College in 1913 following his graduation from Lawrenceville School. He completed a two-year course in Ceramics under Professor Parmelee and in 1915 took a position with the Trenton Fire Clay & Porcelain Company which is a subsidiary company of the J. L. Mott Company. His work began in the laboratory and when he left this Company in October, 1922 he was Manager. In 1920, Mr. Bowman and his brother formed the Bowman Coal Company of Trenton, N. J., and due to the growth of this organization a branch office of this Company was opened in Philadelphia and Mr. Bowman relinquished his ceramic business to devote all of his time to the new work.



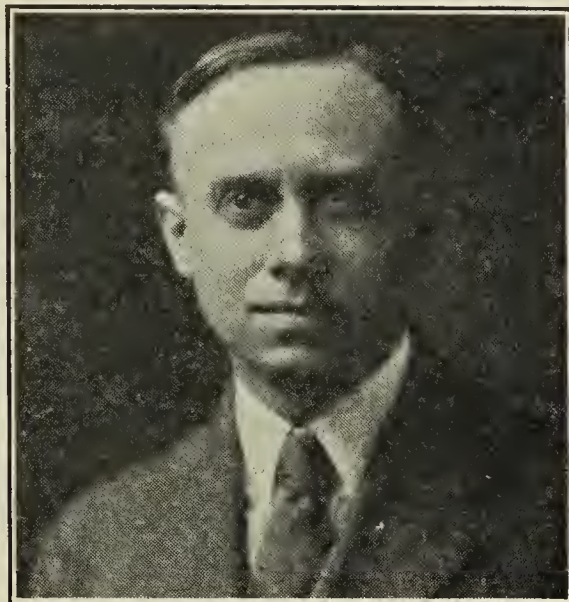
O. O. BOWMAN, 2ND

Mr. Bowman is an active member of the AMERICAN CERAMIC SOCIETY, serving on the Executive Committee of the White Wares Division as well as acting as Chairman

of the Membership Committee. He is also an active member of the New Jersey Clay Workers' Association and Eastern Section of the AMERICAN CERAMIC SOCIETY.

T. A. Klinefelter

T. A. Klinefelter graduated from the Ohio State University and has been active in the ceramic industry through the following positions: Ceramic Engineer with the Westinghouse Electric and Manufacturing Company of East Pittsburgh, Pa., Plant Superintendent of the Atlantic Terra Cotta Company of Tottenville, New York, and Production Manager of the Pottery Department of the J. L. Mott Company of Trenton, New Jersey.



T. A. KLINEFELTER

He is an active member of the AMERICAN CERAMIC SOCIETY, and chairman of Committee on Rules and is the representative from the Terra Cotta Division on the Committee on Data.

Thomas Poole Maynard

T. Poole Maynard was born at Baltimore, Md., 1883. In 1905 Dr. Maynard received his A.B. degree from Johns Hopkins University and his Ph.D. degree in 1909. From 1905 until 1908 he was assistant geologist at Hopkins and Assistant State Geologist of the Georgia Geological Survey from 1909 until 1912. Since that time he has been a Consulting Geologist at Atlanta, Georgia. Dr. Maynard was a member of the Maryland and Virginia Geological Surveys from 1905 until 1909 and in 1907 was with the United States Geological Survey.

Dr. Maynard is an active member of the AMERICAN CERAMIC SOCIETY and is Chairman of the Committee on Geological Surveys of the SOCIETY. He is also a member of the Geological Survey, the Paleontological Society, Mining Engineers, Electro-Chemical Society and others.



A. F. GORTON

Arthur F. Gorton

Arthur F. Gorton was born in Baltimore, Md., and received his A.B. degree in 1912 in Johns Hopkins University. In 1914 he took his A.M. degree, was made Fellow in Physics, 1914-1915, and in 1915 received his Ph.D. degree. During 1915-1916 he was instructor in Physics at the University of Minnesota and held the same position the following year at Johns Hopkins University. From 1917 until 1920 he was ceramist in charge of the laboratory and plant research for the Buckeye Clay Pot Company, Toledo, Ohio and since 1920 has been physicist for the research laboratory of the National Malleable Castings Company, Cleveland, Ohio.

Mr. Gorton is an active member of the AMERICAN CERAMIC SOCIETY and served as Chairman of the Northern Ohio Section of the SOCIETY during 1920. During 1922-1923 he served as Secretary-Treasurer of the Northern Ohio Section.

J. W. Hepplewhite

J. W. Hepplewhite was born at Audenried, Pa. He received his Bachelor's degree in ceramic engineering at Ohio State University in 1920. Since his graduation he has been employed by the Koppers Company's laboratories in Pittsburgh, working on research and standardization of refractories for the by-product coke oven. During 1918 and 1919, he was ceramic assistant at the Bureau of Mines, Ceramic Experiment Station, Columbus, Ohio. Since December 1922, Mr. Hepplewhite accepted a position as ceramic engineer with Johns Manville, Inc., Manville, N. J.



J. W. HEPPLEWHITE

tories of New York City on chemistry and bacteriological work and later became chemist in charge of a new water filtration plant at Newport, R. I. He also filled a similar position for two years at Waco, Texas. For a year and a half Mr. Saxe was in charge of the clay testing laboratory at the Norton Company, and by leave of absence served as filtration plant chemist at the Panama Canal under the department of Operation and Maintenance. Mr. Saxe is again with Norton Company as Supervisor of refractories production and since 1920 has been head of the refractories sales department.

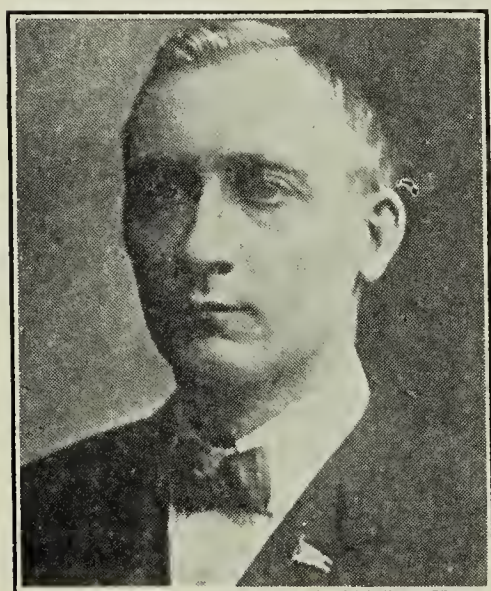
Mr. Saxe is an active member of the AMERICAN CERAMIC SOCIETY and is Secretary of the New England Section of the SOCIETY.

Charles W. Saxe

Charles W. Saxe was graduated from the Rensselaer Polytechnic Institute, Troy, N. Y., in 1910. For two years he was located with the Lederle Labora-



CHARLES W. SAXE



F. G. JAEGER

Frank G. Jaeger

Frank G. Jaeger was born in St. Louis, Mo., in 1872. He was in the employ of the largest stove plant in St. Louis for thirty-two years until he, with several others, organized the Superior Enameled Products Company. Since the beginning of this firm Mr. Jaeger has been Vice-President and General Manager and all formulas used by this firm have been developed by Mr. Jaeger personally.

Mr. Jaeger is an active member of the AMERICAN CERAMIC SOCIETY and since 1921 has been Chairman of the St. Louis Section of the SOCIETY. He is active in the work of the Enamel Division.

Alexander Silverman

Mr. Silverman was born in 1881, and received the following education: University of Pittsburgh (Ph.B. 1902, M.S. 1907), Cornell University (A.B. 1905). From 1902-1904 he was a chemist with Macbeth-Evans Glass Co., conducting researches. Since 1905 he has been on the chemistry faculty of the University of Pittsburgh, and is now head of the Department of Chemistry.

He has lectured at various universities, and is the author of two books. He has also contributed numerous papers to various technical journals.

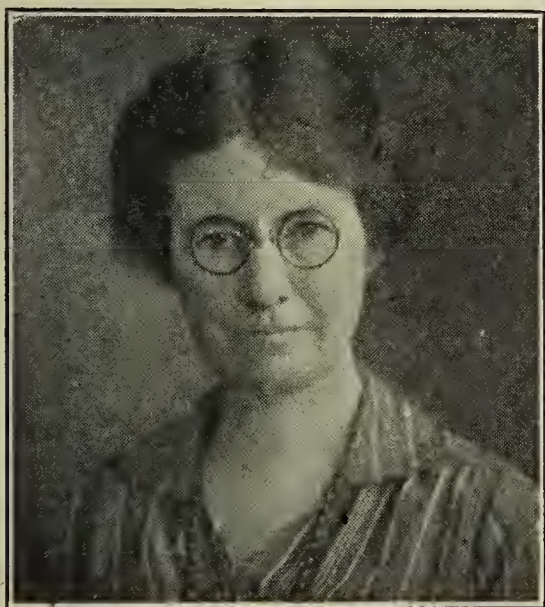
Mr. Silverman is Chairman of the Pittsburgh Section of the AMERICAN CERAMIC SOCIETY, and is also a member of the American Chemical Society, American Electrochemical Society, Technical Photographic and Microscopical Society and the Society of Glass Technology (London).



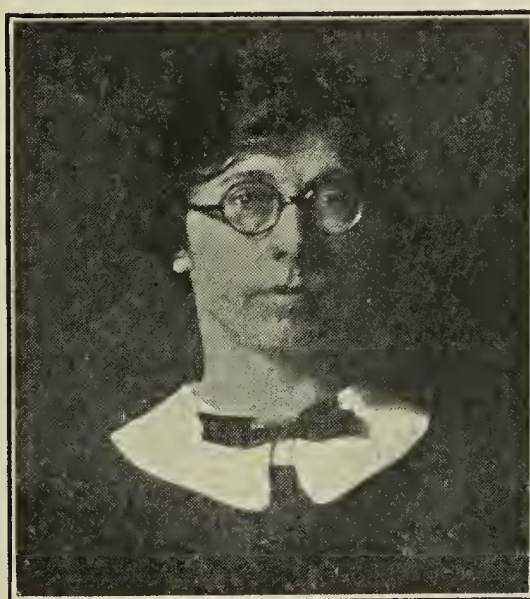
ALEXANDER SILVERMAN Chairman Pittsburgh Section.

OUR OFFICE FORCE

The personnel of the secretarial and editorial office for several years consisted of but one person, Miss Metta L. Seymour. Miss Seymour came to Prof. Orton in the fall of 1899, keeping the records of the SOCIETY as one of the routine tasks. During the later years of Prof. Orton's in-



METTA SEYMOUR



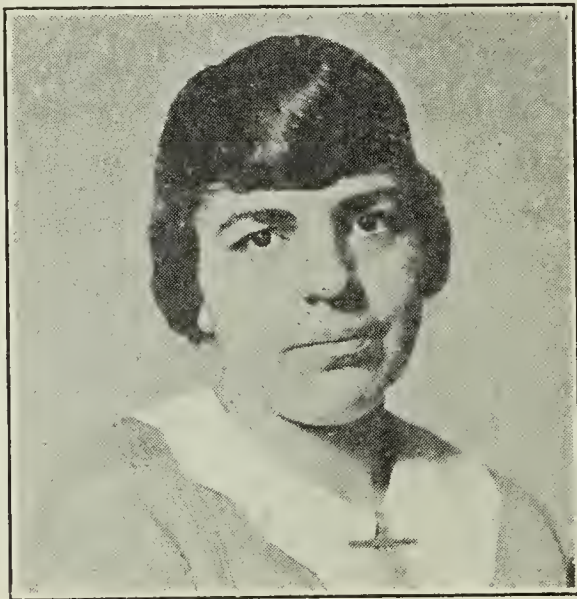
NORAH W. BINNS

cumbency as Secretary and Editor, Miss Seymour devoted most of her time to the affairs of the SOCIETY, and was officially recognized as Assistant Secretary. From 1899 to 1917, she thus served the SOCIETY.

Our present force is here shown. Miss Norah W. Binns, the Assistant Secretary, is well known. She has served in this capacity for five years,

the first four being with her father, who was Secretary of the SOCIETY from 1917 to 1922. She was graduated from Alfred University in 1912.

Miss Emily C. Van Schoick was Assistant Editor under Dr. E. W. Washburn for a few months prior to the consolidation of the two offices



EMILY VAN SCHOICK



HELEN M. ROWLAND

last March. Miss Van Schoick is a graduate of Illinois Wesleyan University, and was at the University of Chicago Press in Chicago for two years before she became editorial assistant for this *Journal*.

Miss Helen Rowland is a recent addition to our force in the dual capacity of second assistant secretary and editor.

CORPORATION MEMBERS

The SOCIETY from the first has continued the policy of low personal membership fees, so that the young men in the industries may have the rights and benefits of membership without inordinate strain on their financial resources. To do this, it is necessary that the manufacturing firms contribute to the support of the SOCIETY, hence the provision for corporation memberships.

The researches reported, and the results of research and educational promotional activities of the SOCIETY have resulted in large savings to the industries. Testimonials of this are frequently heard. It will be readily conceded that if it had not been for the activities of this SOCIETY and similar organizations during the past quarter century, ceramic manufacturing would not have kept pace in competition and with the general cost advances. And certainly the ceramic manufacturers would not today be in so favorable a position for meeting the new, and the often recurring emergency demands on ceramic wares. Whereas, a quarter of a century ago, there were ceramists who had acquired the ability and knowledge to produce certain special wares, such as the finest pottery, efficient grinding wheels, excellent refractories and durable terra cotta, such special

ability was possessed by very few, and these few were employed as specialists who guarded their knowledge very zealously as trade secrets. The ceramic industries could not meet the production demands of today with such uniformly excellent quality of ware if still dependent upon these "experts."

Manufacturing on a large scale within permissible operating costs and producing uniform quality of ware from week to week would have been impossible without the modern equipment and methods, and especially without the modern systems for plant control. Corporations have been very largely financially benefited by the researches of the scientists, artists and engineers whose findings have been pyramided into definite factory methods, devices and mixtures.

This SOCIETY has served and will continue to serve as one of the essential agencies through which such information is cleared and in which it is pyramided. The technical press, the universities, the research bureaus and institutes are essential agencies in the technical advancement in the industries, but none of these are more essential than the technical organizations such as this SOCIETY.

Twenty-five dollars a year does not represent the benefits which accrue to each manufacturing concern from the activities of this SOCIETY, hence it is not from an altruistic motive that corporations give financial support to this SOCIETY as corporation members. Their support is given that their employees may keep abreast with the increasing fund of technical information at the minimum personal cost.

Here are the names of those who were on record December 1, 1922, as corporation members¹ of this SOCIETY:

Abrasive Co. (Louis L. Byers), Tacony & Fraley Sts., Bridesburg, Philadelphia, Pa.
 A C Spark Plug Co. (Taine G. McDougal), Flint, Mich.
 Acme Brick Co. (Douglas F. Stevens), 412 Adams Bldg., Danville, Ill.
 Alexander Hamilton Institute (D. E. Beebe), Astor Place, New York City.
 The Alhambra Tile Co. (J. F. Sheehy, Pres.), Newport, Ky.
 American Dressler Tunnel Kilns, Inc. (Philip Dressler), Cleveland, Ohio.
 American Emery Wheel Works (W. E. Richmond), Providence, R. I.
 American Encaustic Tiling Co. (H. D. Lillibridge), Zanesville, Ohio.
 American Rolling Mill Co. (A. J. Aupperle), Middletown, Ohio.
 American Stove Co. (G. F. Foske, Treas.), 2001 S. Kingshighway, St. Louis, Mo.
 American Terra Cotta and Ceramic Co. (W. D. Gates, Pres.), 1808 Prairie Ave., Chicago, Ill.
 American Trona Corporation (A. A. Holmes, Sales Mgr.), 233 Broadway, New York City.
 Atlantic Terra Cotta Co. (William H. Powell, Pres.), 350 Madison Ave., New York City.
 Auld Co., D. L. (F. Howard Auld), Fifth Street and Fifth Avenue, Columbus, Ohio.

The Babcock & Wilcox Co. (Isaac Harter, Gen. Supt.), 85 Liberty St., New York City.
 Baker Bros. Glass Co. (W. G. Baker, Pres.), Okmulgee, Okla.
 Batchelder-Wilson Co. (Ernest A. Batchelder), 2633 Artesian St., Los Angeles, Cal.
 Bausch & Lomb Optical Co. (John C. Kurtz), Rochester, N. Y.
 Beaver Falls Art Tile Co. (F. W. Walker, Jr.), Beaver Falls, Pa.
 Benjamin Electric Mfg. Co. (A. E. Clarke), Des Plaines, Ill.
 Big Savage Fire Brick Co. (D. A. Benson, Vice-Pres.), Frostburg, Md.
 Bird & Co. (B. A. White), Kumardhubi Fireclay & Silica Wks. Ltd., Calcutta, India.
 Bowman Coal Co. (Robert T. Bowman, Pres.), Broad St. Bank Bldg., Trenton, N. J.
 Brick & Clay Record (E. G. Zorn), 407 S. Dearborn St., Chicago, Ill.
 Brunner Mond & Co. Ltd. (L. A. Munro), Northwich, England.
 Buckeye Clay Pot Co. (A. S. Zopfi), Toledo, Ohio.
 Buffalo Pottery (L. H. Bown, Gen. Mgr.), Buffalo, N. Y.
 W. G. Bush & Co. (W. H. Herbert), 174 Third Ave. North, Nashville, Tenn.

Canadian General Electric Co., Peterborough, Canada.
 Canonsburg Pottery Co. (W. C. George), Canonsburg, Pa.

¹The name of the individual representative is given in parentheses after the name of the company.

The Canton Brick & Fireproofing Co. (W. F. Demuth, Pres.), New Philadelphia, Ohio.
 The Canton Stamping & Enameling Co. (E. F. Hoerger), Canton, Ohio.
 The Carborundum Co. (Frank J. Tone), Niagara Falls, N. Y.
 The Champion Porcelain Co. (Jos. A. Jeffery), Detroit, Mich.
 Chicago Crucible Co. (A. F. Hottinger), 2525 Claybourn Ave., Chicago, Ill.
 Chicago Pottery Co. (F. J. Clifford), 1924 Claybourn Ave., Chicago, Ill.
 Chicago Retort and Fire Brick Co. (John H. Cavender, Vice-Pres.), 208 S. LaSalle St., Chicago, Ill.
 The Clay Products Co. (Geo. W. Shoemaker, Vice-Pres.), Brazil, Ind.
 Clay Service Corporation (M. E. Gates, Pres.), 138 N. LaSalle St., Chicago, Ill.
 Claycraft Mining & Brick Co. (Wm. T. Mathews), 907 Hartman Bldg., Columbus, Ohio.
 Clinchfield Products Corp. (Charles Ingram), 350 Madison Ave., New York City.
 The Colonial Co. (Wm. H. Robinson, Sec.-Treas.), East Liverpool, Ohio.
 Conkling-Armstrong Terra Cotta Co. (Thos. F. Armstrong, Pres.), 410 Denckla Bldg., Philadelphia, Pa.
 Cook China Company (James Turner, Vice-Pres.), Trenton, N. J.
 Coonley Mfg. Co. (T. A. McDonald), Cicero, Ill.
 Cortland Grinding Wheels Corp. (E. Bertram Pike, Pres.), Chester, Mass.
 Crescent Refractories Co. (R. F. Hess), Curwensville, Pa.
 Crown Potteries Co. (A. Davidson, Sec.), Evansville, Ind.

Denny Renton Clay and Coal Co. (R. A. Swam, Gen. Mgr.), Pioneer Bldg., Seattle, Wash.
 The Denver Terra Cotta Co. (Geo. P. Fackt, Vice-Pres.), West First and Umatilla Sts., Denver, Colo.
 Dings Magnetic Separator Co. (R. A. Manegold), Milwaukee, Wis.
 H. L. Dixon Co. (D. W. Loomis, Treas.), Box 140, Pittsburgh, Pa.
 Joseph Dixon Crucible Co. (Malcolm McNaughton), Jersey City, N. J.
 B. F. Drakenfeld & Co., Inc. (B. F. Drakenfeld, Jr.), 50 Murray St., New York City.
 Dunn Wire Cut Lug Brick Co. (Frank B. Dunn), Conneaut, Ohio.

East Liverpool Potteries Co. (Bernard S. Purinton), Wellsville, Ohio.
 The Edgar Plastic Kaolin Co. (D. R. Edgar), Metuchen, N. J.
 Electric Porcelain & Mfg. Co. (Henry T. Paiste, Pres.), Trenton, N. J.
 Electrical Refractories Co. (C. W. Williams, Treas.), East Palestine, Ohio.
 Elgin Butler Brick and Tile Co. (John F. Butler, Pres.), Austin, Texas.
 Elyria Enameled Products Co. (Wm. E. Gray), Elyria, Ohio.
 Charles Engelhard, Inc. (R. N. Newcomb), 30 Church St., New York City.
 English China Clays Sales Corp. (W. F. Harris, Treas.), 33 West 42nd St., New York City.
 Enterprise White Clay Co. (H. S. Donaldson, Treas.), Real Estate Trust Bldg., Philadelphia, Pa.
 Eureka Flint and Spar Co. (Frank W. Thropp), Trenton, N. J.

Federal Terra Cotta Co. (DeForest Grant, Pres.), 101 Park Ave., New York City.
 Edward Ford Plate Glass Co. (C. E. Husted), Rossford, Ohio.
 Fords Porcelain Works, (Abel Hansen, Pres.), Perth Amboy, N. J.
 The French China Co. (Ernest Hundley), Sebring, Ohio.
 Frink Pyrometer Co., Lancaster, Ohio.

General Ceramics Co. (Lewis Albrecht), 50 Church St., New York City.
 W. S. George Pottery Co. (W. C. George), East Palestine, Ohio.
 Gillinder Bros. (James Gillinder), Port Jervis, N. Y.
 Gladding McBean & Co. (Atholl McBean, Sec.), Crocker Bldg., San Francisco, Cal.
 Gleason-Tiebout Glass Co. (C. H. Tiebout, Jr.), 99 Commercial St., Brooklyn, N. Y.
 Globe Brick Co., Box 765, East Liverpool, Ohio.
 The Golding Sons Co. (J. M. Manor), East Liverpool, Ohio.
 Golding-Keene Co. (Charles E. Golding), Keene, N. H.

The Haeger Potteries, Inc. (E. H. Haeger, Pres), Dundee, Ill.
 The Hall China Co. (M. W. Thompson, Sec.-Treas.), East Liverpool, Ohio.
 Hanovia Chemical and Mfg. Co. (W. Riehl), Chestnut St. and N. J. R. Ave., Newark, N. J.
 Harbison-Walker Refractories Co. (Kenneth Seaver), Pittsburgh, Pa.
 Hardinge Co., Inc. (Harlowe Hardinge, Vice-Pres.), 120 Broadway, New York City.
 The Harker Pottery Co. (H. N. Harker), East Liverpool, Ohio.
 The Harshaw, Fuller & Goodwin Co. (W. A. Harshaw), 545 Hanna Bldg., Cleveland, Ohio.
 Hazel-Atlas Glass Co. (J. H. M. Nash), Wheeling, W. Va.
 Heidenkamp Plate Glass Co. (Jos. Heidenkamp, Pres.), Springdale, Pa.
 Homer-Laughlin China Co. (W. E. Wells), East Liverpool, Ohio.
 L. J. Houze Convex Glass Co. (Roger J. Houze), Point Marion, Pa.
 Huntington Tumbler Co. (E. L. Zihlman, Pres.), Huntington, W. Va.

Illinois Glass Co. (Ray S. Godard), Alton, Ill.
 Ingram-Richardson Mfg. Co. (Ernest Richardson, Vice-Pres. and Treas.), Beaver Falls, Pa.
 Iron City Sanitary Mfg. Co., 1514 Oliver Bldg., Pittsburgh, Pa.

Jefferson Glass Co. (C. H. Blumenauer, Pres.), Follansbee, W. Va.
 Johnson Porter Clay Co. (Lance Turnbull), McKenzie, Tenn.
 Jones Hollow Ware Co. (M. B. Meanley), Baltimore, Md.

O. W. Ketcham (O. W. Ketcham), 125 North 18th St., Philadelphia, Pa.
 Kier Fire Brick Co. (P. S. Kier), 2243 Oliver Bldg., Pittsburgh, Pa.
 Edwin M. Knowles China Co. (Harry Watkin), Newell, W. Va.
 Knowles, Taylor & Knowles Co. (Homer J. Taylor), East Liverpool, Ohio.
 Koken Companies (Geo. D. Chisholm, 1st Vice-Pres.), 2528 Texas Ave., St. Louis, Mo.

Laclede-Christy Clay Products Co. (John L. Green, Pres.), St. Louis, Mo.
 The Libbey Glass Mfg. Co. (George Dougherty), Toledo, Ohio.
 The Limoges China Co. (W. I. Gahr), Sebring, Ohio.
 A. J. Lindemann & Hoverson Co. (W. C. Lindemann), Milwaukee, Wis.
 Lindsay Light Co. (Jos. M. Sherburne), 161 E. Grand Ave., Chicago, Ill.
 Livmore Fire Brick Works (N. A. Dickey, Gen. Mgr.), 604 Mission St., San Francisco, Cal.
 Los Angeles Pressed Brick Co. (Howard Frost, Pres.), 6th Floor, Frost Bldg., Los Angeles, Cal.
 The Louthan Manufacturing Co. (Wm. B. Louthan), East Liverpool, Ohio.

- D. E. McNicol Pottery Co., East Liverpool, Ohio.
 Macbeth-Evans Glass Co. (C. R. Peregrine), Pittsburgh, Pa.
 John Maddock & Sons (H. E. Maddock, Vice-Pres.), Trenton, N. J.
 Thomas Maddock's Sons Co. (C. S. Maddock, Jr.), Trenton, N. J.
 Maine Feldspar Co. (Norman G. Smith), Auburn, Maine.
 Mason City Brick and Tile Co. (B. C. Keeler), Mason City, Iowa.
 Massillon Stone and Fire Brick Co. (T. C. Eayrs, Gen. Mgr.), Massillon, Ohio.
 Matawan Tile Co. (B. K. Eskesen), Matawan, N. J.
 Metal and Thermit Corp. (H. F. Staley), 120 Broadway, New York City.
 Michigan Stove Co. (Emmet Dwyer), Detroit, Mich.
 Midland Terra Cotta Co. (Walter S. Primley), 1515 Lumber Exch. Bldg., Chicago, Ill.
 Millville Bottle Works (W. F. Wheaton), 7th and Main Sts., Millville, N. J.
 Mississippi Glass Co. (R. D. Humphreys), 220 Fifth Ave., New York City.
 Mitchell Clay Mfg. Co. (Wm. F. Knoesel), 5627 Manchester Ave., St. Louis, Mo.
 The Mogadore Insulator Co. (F. W. Butler, Pres.), Mogadore, Ohio.
 Monongah Glass Co. (R. T. Cunningham, Sec.-Treas.), Fairmont, W. Va.
 Moore & Munger (Melville Marks), 29 Broadway, New York City.
 The Mosaic Tile Co. (J. M. Morton), Zanesville, Ohio.
 J. L. Mott Co. (W. J. J. Bowman, Gen. Works Mgr.), Trenton, N. J.
 The National China Co. (Samuel B. Larkins, Sec.), Salineville, Ohio.
 National Fireproofing Co. (W. H. Foster), 1126 Fulton Bldg., Pittsburgh, Pa.
 National Lime Association (M. E. Holmes), 918 G Street N. W., Washington, D. C.
 New York Architectural Terra Cotta Co. (R. F. Dalton, Pres.), 401 Vernon Ave., Long Island City, N. Y.
 Niles Fire Brick Co. (P. J. Sheehan), 165 East Park Ave., Niles, Ohio.
 Nippon Gaishi Kwaisha (M. Ezoi, Mgr.), Atsuta Higashimatch, Nagoya City, Japan.
 Nippon Toki Kwaisha (M. Ise, Mgr.), Noritake, Nagoya City, Japan.
 North Carolina Geological and Economic Survey (Joseph Hyde Pratt, Director), Chapel Hill, N. C.
 Norton Co. (Arthur T. Malm), Worcester, Mass.
 Ohio Pottery Co. (C. D. Fraunfelter), Zanesville, Ohio.
 Old Bridge Enameled Brick & Tile Co. (Hamilton Hazlehurst), Old Bridge, N. J.
 The Onondaga Pottery Co. (B. E. Salisbury), Syracuse, N. Y.
 Owen China Co. (F. B. Cross), Minerva, Ohio.
 Paper Makers Importing Co., Inc. (Charles Brian, Vice-Pres.), 640 N. 13th St., Easton, Pa.
 Parker Russell Mining & Mfg. Co. (Lemon Parker), 603 Laclede Gas Bldg., St. Louis, Mo.
 Pass & Seymour, Inc. (B. E. Salisbury), Solvay, N. Y.
 The Patterson Fdry. & Mch. Co. (Richard L. Cawood, Pres.), East Liverpool, Ohio.
 Pennsylvania Pulverizing Co. (Wm. J. Woods), Lewistown, Pa.
 Pennsylvania Salt Mfg. Co., 615 Union Arcade Bldg., Pittsburgh, Pa.
 Perth Amboy Tile Co. (C. H. Rasmussen), Perth Amboy, N. J.
 The Pfaudler Co. (N. G. Williams), Rochester, N. Y.
 Philadelphia Drying Machinery Co. (Walter W. Sibson), Philadelphia, Pa.
 Phoenix Glass Co. (A. H. Stewart), Pittsburgh, Pa.
 Pittsburgh High Voltage Insulator Co. (W. H. Lowry), Derry, Pa.
 The Pittsburgh Plate Glass Co. (C. E. Fulton), Pittsburgh, Pa.
 The Pope-Gosser China Co. (G. C. Mitchell, Pres.), Coshocton, Ohio.
 The Porcelain Enamel and Mfg. Co. (Karl Türk, Vice-Pres.), O'Donnell and Eighth Sts., Baltimore, Md.
 Portland Stove Works (Harry A. Montag), Portland, Ore.
 The Portsmouth Stove and Range Co. (John B. Krauss, Vice-Pres.), Portsmouth, Ohio.
 Potters Supply Co. (Dewitt C. Irwin), East Liverpool, Ohio.
 Proctor & Schwartz, Inc. (E. B. Ayres, 2nd Vice-Pres.), 7th St. and Tabor Rd., Philadelphia, Pa.
 The Product Sales Co. (Joseph Rodgers), 206 Water St., Baltimore, Md.
 Reading Firebrick Works, Reading, Pa.
 Reliance Firebrick and Pottery Co. Ltd., 8 Clive Row, Calcutta, India.
 Robertson Art Tile Co. (A. D. Forst, Pres.), Box 848, Trenton, N. J.
 Roessler & Hasslacher Chemical Co. (Werner Malsch), 709-717 Sixth Ave., New York City.
 The Rookwood Pottery Co. (Stanley G. Burt), Mount Adams, Cincinnati, Ohio.
 Russell Engineering Co. (A. W. Buckingham), 1624 Railway Exchange Bldg., St. Louis, Mo.
 Salem China Co. (F. H. Sebring), Salem, Ohio.
 The John Sant & Sons Co. (Thos. H. Sant, Pres.), East Liverpool, Ohio.
 The Saxon China Co. (Ray Y. Cliff, Treas. and Gen. Mgr.), Sebring, Ohio.
 Schaffer Engineering & Equipment Co. (A. A. Alles, Jr.), 2828 Smallman St., Pittsburgh, Pa.
 Seaboard Fuel Corp. (Geo. W. Dilks, Jr., Vice-Pres.), 1610 Spruce St., Philadelphia, Pa.
 The Sebring Pottery Co. (Charles L. Sebring), Sebring, Ohio.
 Smith-Phillips China Co. (W. H. Phillips), East Liverpool, Ohio.
 South Amboy Terra Cotta Co. (Peter C. Olsen), 150 Nassau St., New York City.
 The H. C. Spinks Clay Co., Newport, Ky.
 Springfield Paving Brick Co. (W. P. Whitney, Pres.), Box 403, Springfield, Ill.
 Square D Company (A. P. Ball, Asst. Gen. Mgr.), Peru Plant, Peru, Ind.
 Standard Pottery Co. (D. M. Cronin), East Liverpool, Ohio.
 Standard Sanitary Mfg. Co. (G. C. Kalbfleisch), Tiffin Works, Tiffin, Ohio.
 Standard Sanitary Mfg. Co. (Theodore Tafel, Jr.), 551 Preble Ave., N. S., Pittsburgh, Pa.
 Star Porcelain Co. (Herbert Sinclair), Trenton, N. J.
 The Stark Rolling Mill Co. (R. B. Dimmick), Canton, Ohio.
 Stevens Bros. & Co. (W. S. Stapler, Pres.), Stevens Pottery, Ga.
 St. Louis Terra Cotta Co. (R. F. Grady), 5811 Manchester Ave., St. Louis, Mo.
 Stockton Fire Brick Co. (John T. Roberts), 915 Rialto Bldg., San Francisco, Cal.
 Streater Clay Mfg. Co., Streater, Ill.
 The Strong Manufacturing Co. (W. U. Pfaeffli, Treas. and Gen. Mgr.), Sebring, Ohio.
 Sunflower Glass Co. (Frank Bostock, Pres.), Sapulpa, Okla.
 The Taylor, Smith & Taylor Co. (W. L. Smith, Jr.), Chester, W. Va.
 R. Thomas & Sons Co. (G. Richard Thomas), East Liverpool, Ohio.

Toyo Toki Kwaisha (S. Momoki), Shinozaki, Kokura City, Japan.
 Trenton Flint & Spar Co. (R. H. Wainford), 203 East State Street, Trenton, N. J.
 Trenton Potteries Co. (John A. Campbell, Pres.), Trenton, N. J.
 Tropico Potteries Inc. (F. B. Ortman, Vice-Pres.), Glendale, Cal.
 W. S. Tyler Co., (F. P. Nickerson), Cleveland, Ohio.

U. S. Glass Co. (G. Oliver Challinor), South Ninth Street, Pittsburgh, Pa.
 U. S. Metals Refining Co. (Francis R. Pyne), Chrome, N. J.
 U. S. Smelting Furnace Co. (Walt Marsh), Belleville, Ill.
 Universal Clay Products Co. (Frank E. Pyatt), Sandusky, Ohio.
 Universal Sanitary Mfg. Co. (C. J. Kirk, Pres.), New Castle, Pa.

Veritas Firing System (Herbert Forester), Prospect Laboratories, Trenton, N. J.
 The Vitreous Enameling Co. (R. D. Landrum, Vice-Pres.), Cleveland, Ohio.
 Vitro Manufacturing Co. (Josef Vollkommer), Bessemer Bldg., Pittsburgh, Pa.
 Vodrey Pottery Co. (Wm. E. Vodrey), East Liverpool, Ohio.
 The Vollrath Co. (Dewitt F. Riess, Sec.), Sheboygan, Wis.

The Wahl Co. (Robert Back), 1800 Roscoe St., Chicago, Ill.
 Wainford Darling Co. (C. Harry Darling, Pres.), Trenton, N. J. .
 Warwick China Co. (C. E. Jackson), Wheeling, W. Va.
 The Wehrle Co. (W. W. Wehrle), Newark, Ohio.
 The West End Pottery Co. (W. E. Cuning, Pres.), East Liverpool, Ohio.
 Western Electric Co. (W. F. Horford, Technical Supt.), Hawthorne Sta., Chicago, Ill.
 Western Stoneware Co. (I. F. Dains), Monmouth, Ill.
 Whittall-Tatum Co. (Geo. S. Bacon), Millville, N. J.
 Whiting-Mead Commercial Co. (W. H. Mead, Vice-Pres.), 2035 E. Vernon Ave., Los Angeles, Cal.
 H. R. Wyllie China Co. (H. R. Wyllie), Huntington, W. Va.

THE AMERICAN CERAMIC INDUSTRIES

BY F. H. RIDDLE¹

Definition of the Term "Ceramics"

The term "Ceramics" has a much more definite meaning now than it did when the SOCIETY was founded twenty-five years ago. It is gratifying to most of us to know that the members of our SOCIETY have played an important part in bringing about this condition. Most of us are familiar with the definition of the word ceramics but it is not out of place to repeat it at this time.

The dictionary definition as reviewed by our Committee on the definition of the term first appeared in the English language about the middle of the 19th century, apparently through adoption from the French (Fr. *ceramique*). In accordance with modern language usage, as known by the lexicographers, the term "ceramics" is employed to designate that portion of the plastic arts which embraces the production and decoration of all objects formed by the molding, modeling and baking of clay. According to lexicographers the term is, therefore, practically synonymous with the clay working of the art of the potter, and there is no indication in any of the dictionary definitions, of a broader significance than this.

The Committee further states that the term "ceramics" as used in modern technology, has acquired, at all events in this country, a much wider significance than that indicated by the dictionary definition. They state further "...we may, therefore, properly define and describe the ceramic industries as those industries which manufacture products by the action of heat on raw materials, most of which are of an earthy nature, while of the constituents of these raw materials the chemical element, silicon, together with its oxide and the compounds thereof (silicates), occupies a predominant position." In accordance with this definition we may enumerate among the products of the ceramic industries the following: Their list includes burned clay products, cementing materials, glass, enameled metal, refractory materials, abrasives and electrical and thermal insulating products in the manufacture of which clay enters in as an important element. Oldfather's article² on the word "ceramics" is interesting in the above connection.

In the September issue of this *Journal* is published the report of the Committee on an International Definition of the term "Ceramic," as given by Dr. E. W. Washburn, the AMERICAN CERAMIC SOCIETY's representative, at the Third Conference of the International Union of Pure and Applied Chemistry, held at Lyons, France, on June 27 to July 2, 1921. The report is as follows:

¹ Read before the Chemical Exposition, New York City, September, 1922.

² *Jour. Amer. Ceram. Soc.*, 3 [7], 537.

The committee had before it an excellent French translation of the report of the AMERICAN CERAMIC SOCIETY'S committee on definition of the term "ceramic." This report was printed and placed in the hands of all the delegates in attendance at Lyons. The committee approved unanimously the recommendations contained in this report and voted that it serve as the basis of discussion of the question which should be brought before the next meeting of the Union for final consideration, after each country belonging to the Union had had an opportunity to study the report and contribute to the discussion.

Ceramic Industries

The following outline shows briefly the various products which are classed as ceramic materials: (1) Clay products (exclusive of refractories), (2) glass, (3) enameled metal, (4) abrasives and (5) refractories. Some also believe that the production of cement and lime would come under the same headings.

Clay Products

Porcelain, whiteware and kindred products

Hotel china and vitrified tableware

Whiteware or semi-vitreous tableware

Floor and wall tile

Electrical porcelain

Specialties, as spark plug porcelain, etc.

Chemical porcelain

Refractory porcelain, such as pyrometer protection tubes

Chemical stoneware

Stoneware

Yellowware

Art pottery

Hollow ware

Sewer pipe

Partition tile

Drain tile

Terra cotta for building purposes

Brick

Common brick

Face brick

Fire brick (see refractories)

Paving brick

Glass

Building glass

Window glass, plate glass, cast and rolled glass

Pressed and blown glass

Tableware, jelly glasses, tumblers, goblets, bar goods, lamps, chimneys, lantern globes, electric globes, electric bulbs, shades, globes, opal ware, art ware, decorated glassware

Bottles, jars, druggists' ware, demijohns, etc.

Enameled Metal

Sanitary ware, bath tubs, wash-stands, etc.

Cooking ware, enameled pans, etc.

Chemical ware, vats, stills, etc.

Abrasives

Materials such as silicon carbide, alundum, emery, and other products together with the products manufactured from them by the bonding with an earthy material.

Refractories

Ground refractories as fire clay, chrome, magnesite, etc.

Brick

Clay, magnesite, silica, chrome, alundum, silicon carbide, spinel, sillimanite, etc.

Blocks, glass pots and special refractories

Ceramic products play a wider rôle in building and construction than do any other products with the possible exception of steel.

Value of the Products

An attempt has been made to show the value of these products. However, since the reports are for the year 1919-20, it must be remembered that these years were not normal. The increase in the value of clay products since 1915 has been largely due to the increase in price, although most of the products have increased in quantity also. During 1918 pottery was the only clay product which was not restricted. Products for building purposes were severely restricted in output during the World War; however, the increase in building activities during 1920 caused large increases in the output of clay products for this purpose with the exception of fire brick which showed a decrease. This was due not only to the strike in the steel industry, its chief consumer, but also on account of the abnormal demand during the War. In the glass industry the increase from 1914 to 1919 is also due to increases in value on account of wartime conditions.

Abrasives showed a decline after the War on account of the depression in the steel and metal manufacturing lines.

The values of the products manufactured during 1920, unless otherwise marked, as given by various government reports are as follows:

Clay products (exclusive of refractories)	\$320,254,214.00
Glass, 1919	261,884,080.00
Enameled metal	42,559,569.00
Abrasives (natural, artificial and manufactured)	44,971,343.00
Refractories	53,415,888.00
Total	<u>\$723,085,094.00</u>

A detailed list of some of the ceramic products is of interest.

Clay products (including refractories)

Porcelain pottery, etc.

Red earthenware	\$1,766,919.00
Red and brown white-lined cooking ware	715,902.00
Stoneware and yellow and Rockingham ware	5,475,660.00
Chemical stoneware and porcelain	1,273,511.00
White ware, including C. C. ware, etc.	38,323,880.00
China, bone china, Delft and Belleek ware	11,340,093.00
Sanitary ware	22,014,651.00
Porcelain electrical supplies	20,218,924.00
Miscellaneous	5,587,136.00
Total	<u><u>\$106,716,676.00</u></u>

Terra Cotta (architectural)

\$10,851,902.00

Hollow ware

Sewer pipe	\$25,171,015.00
Tile	12,470,036.00
Drain tile	12,524,641.00
Building tile	27,312,007.00
Total	<u><u>\$77,477,699.00</u></u>

Brick

Common brick	\$82,216,230.00
Face and fancy brick	20,552,372.00
Paving and vitrified brick	12,678,557.00
Fire brick	53,415,888.00
Miscellaneous	9,524,336.00
Total	<u><u>\$266,953,426.00</u></u>

Glass, 1919

Building glass	\$83,713,115.00
Pressed and blown glass	70,748,861.00
Bottles and jars	94,670,389.00
Other products	12,751,715.00
Total	<u><u>\$261,884,080.00</u></u>

Enameled Metal	
Enameled ware	\$37,636,584.00
Bath tubs	2,955,953.00
Lavatories and sinks	1,967,032.00
Total	<u>\$42,559,569.00</u>
Abrasives	
Artificial	\$7,492,164.00
Natural	4,299,812.00
Emery and other abrasive wheels	30,949,270.00
Grindstones	1,369,423.00
Millstones	66,896.00
Hones and whetstones	793,778.00
Total	<u>\$44,971,343.00</u>

A glance at the above list gives one an idea of the enormous value of the product manufactured every year in the United States and the diversified interests that are dependent upon ceramic products for many of the essentials of their business.

Possibly the most important ceramic products from a manufacturing standpoint are refractories, and, unfortunately, the product that the consumer pays very little attention to. Every power house is dependent upon the fire brick in their boilers for continuation of uninterrupted service and yet the smaller users are very apt to buy these brick upon a price consideration only, assuming that all so-called fire brick are equally good.

Growth of the Industry

The growth of the industry is probably best shown by a study of the various government reports, as plotted on curves shown in Figs. 1 and 2.

Clay Described

Practically all branches of the ceramic industry involve the use of clay as a raw material so that, on account of its importance in this respect, a description of clay is of interest.

Briefly, pure clay is a hydrated aluminum silicate of the formula— $\text{Al}_2\text{O}_3, 2\text{SiO}_2, 2\text{H}_2\text{O}$ —having a chemical composition by per cent of

46.5% Silica
39.6% Alumina
13.9% Water

This pure material is spoken of as kaolin; however, the large bulk of clays are very impure and only good for manufacturing lower grades of heavier clay products. From the industrial standpoint clays may be divided into several classes. These are given by Bleining as follows:

PRODUCTION.

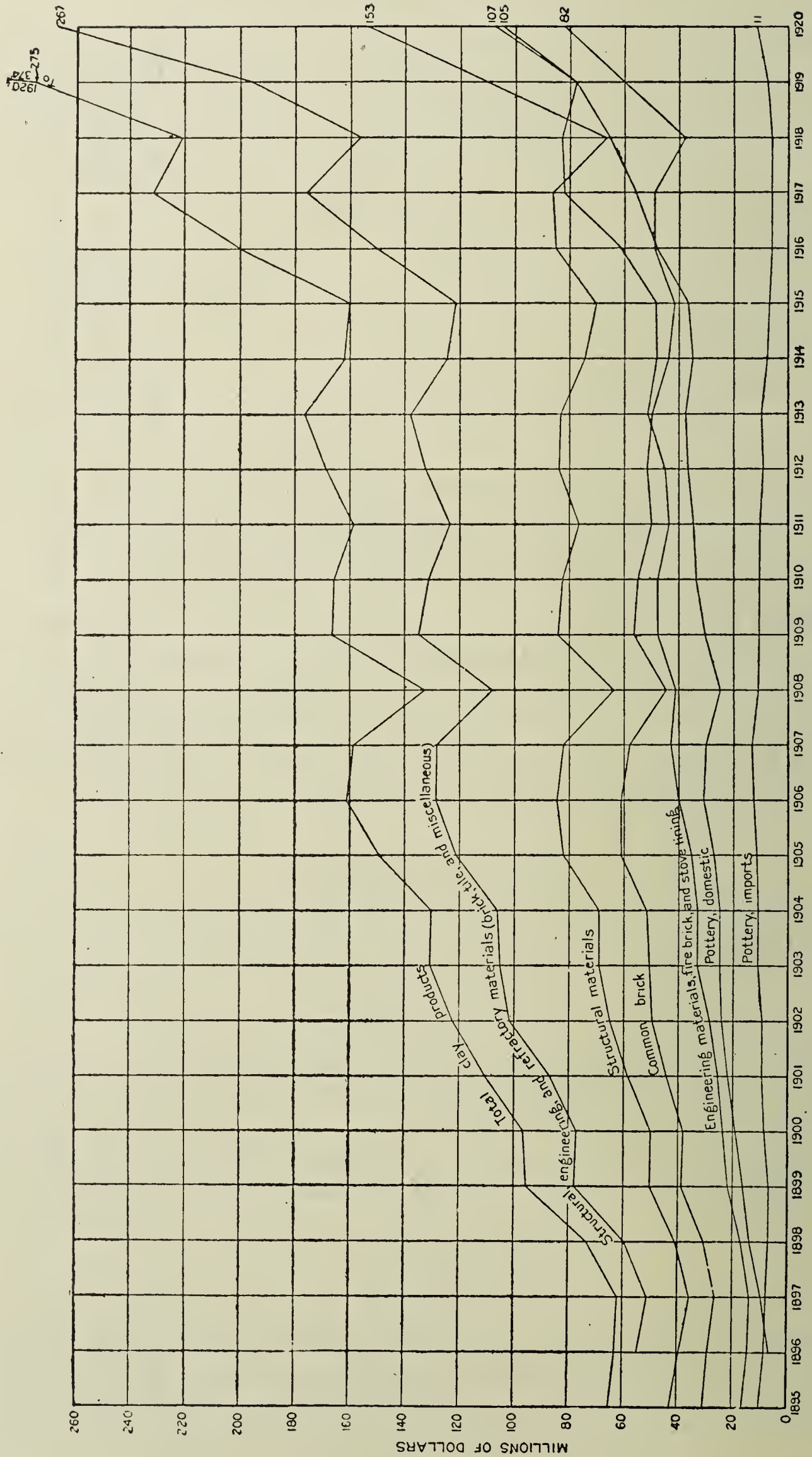


FIG. 1.—Value of clay products sold in the United States, 1895-1920.
(From Report of the United States Geological Survey.)

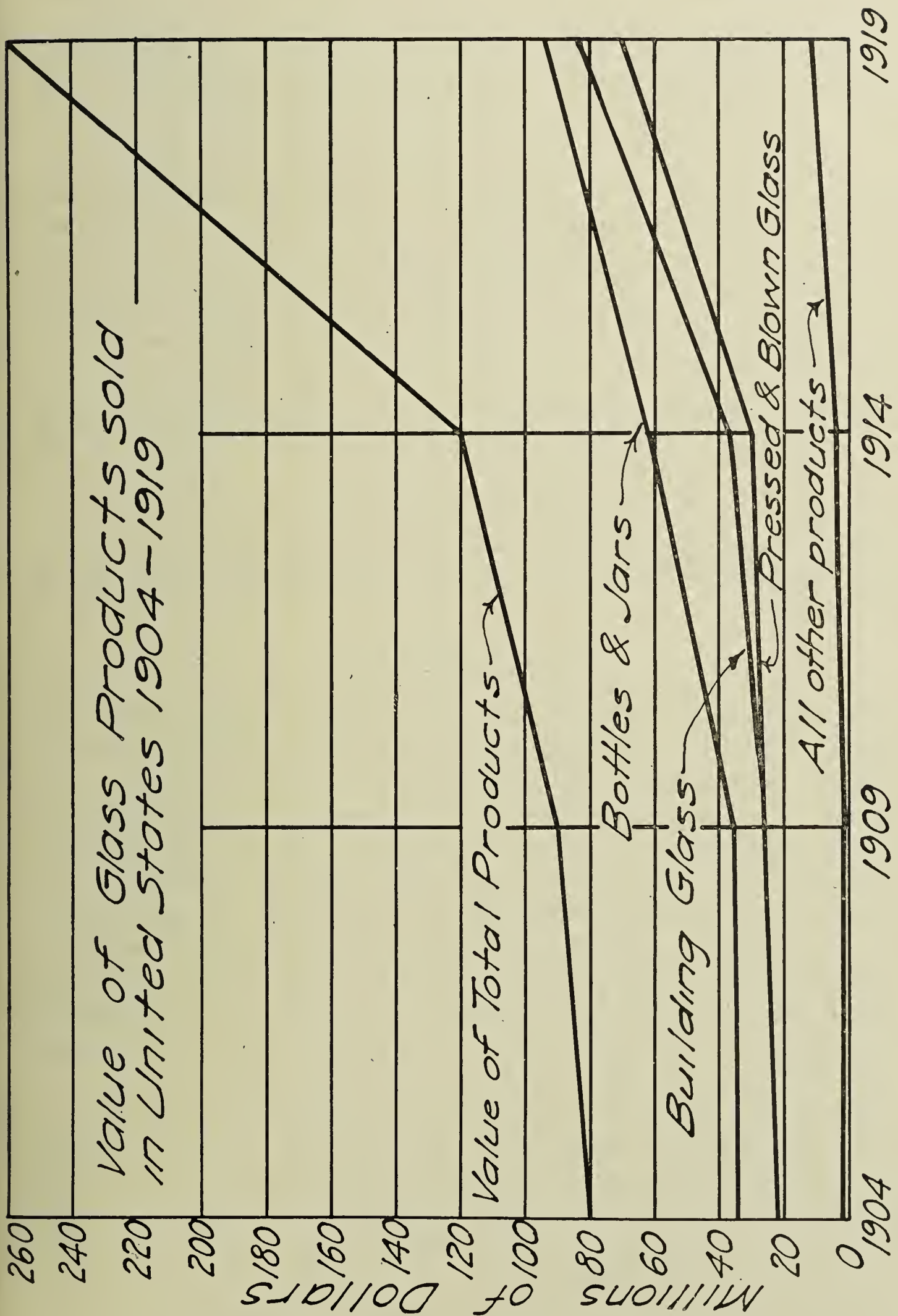


FIG. 2.

1. **Primary Kaolins.**—Usually white burning, very refractory, and of low plasticity and strength.

2. **Plastic Kaolins.**—Not as white burning as primary clays. May be very plastic.

3. **Clays of the Fire-clay Type.**—Ranging from materials of high refractoriness to those inferior in this respect. Certain highly refractory clays called flint clays, are almost lacking in plasticity. Very plastic clays, called ball or bond clays.

4. **Shales.**—Fine-grained, hard clays, showing well-defined cleavage and often slate-like in appearance. They differ widely as to composition. Many ferruginous shales are sources of the best paving brick. Shales, as a rule, are uniform over comparatively large areas, and hence have great industrial importance.

5. **Alluvial Clays.**—Of recent geological origin and found principally in old and new river valleys. Vary widely in composition and physical behavior, from clays of excellent plasticity to very sandy materials. As a rule, unsuitable for paving brick. Usually burn to a red color.

6. **Glacial Clays.**—Heterogeneous mixtures of clay with various rock debris. Frequently calcareous, causing clay to burn to a cream or buff color. As a class difficult to work and hence suitable only for crude products.

7. **Loess Clays.**—Wind-blown deposits, usually siliceous and hence of low plasticity. Used only for common bricks.

The United States is not deficient in any of the types of clay, although the distribution, of course, is not uniform, so that many states are lacking entirely in certain kinds of raw material.

Standards for Purchase

Considerable work has been done by the various technical societies in the country to develop suitable specifications for the purchase of ceramic materials. Perhaps the American Society for Testing Materials has done more than any other group. The several branches of the ceramic industry have established Trade Associations or similar organizations and these have done a great deal along the same line. Considerable research work has also been done by these organizations; however, this will be mentioned later. Secretary Hoover has accomplished a great deal in his recent moves to standardize and simplify products and he has received the enthusiastic coöperation of the ceramic manufacturers. A great deal has been accomplished in the paving brick industry by the elimination of many special shapes and by the standardization of the necessary shapes.

Many laboratories, government bureaus, technical societies and consumers have worked on the standard tests and specifications for the purchase and use of refractories and have developed standards that are satisfactory to both the consumer and manufacturer; however, many small consumers do not see the necessity of undertaking these tests and quite often get into serious difficulty.

President C. D. Young in his Annual Address to the American Society for Testing Materials in June, 1922, made some very pertinent remarks which should not be lost sight of.

He states:

In overcoming the prejudice against standardization, the manufacturer has learned that it is possible for him to produce a far better quality of product, and at the same time greatly reduce his expenses through mass production. This lower cost makes it possible not only to offer to the public better materials at lower unit prices, but also to maintain at the same time higher wages for labor.

Although standardization restricts the varieties for selection, it permits concentration of thought and skill upon design, so that the product may be more economically and efficiently handled. It also reduces the maintenance cost of the finished structure by simplifying the stocks necessary for their maintenance. These well-established standards have established that factor of safety which is essential for the engineer in making the finished product.

American standards of quality, having forced recognition throughout the world, have stabilized production and employment through the broadening effect of increased markets, and have made it safe for manufacturers to accumulate stocks during dull periods, when, without such standards, such a policy would have been extremely hazardous not only to the manufacturer but also to the general public.

Industries Described

The Pottery Industry in the United States includes several types such as stoneware, majolica, whiteware and porcelain. For a time it looked as if the old-fashioned stoneware, such as butter jars, jugs, etc., was becoming extinct; however, this industry has again become active as many homes are finding use for the ten and twenty gallon crocks. The chemical stoneware industry has developed to an extensive degree since the outbreak of the War and has made this country independent of importation. Very difficult shapes are manufactured, such as complete condensing coils; large pieces, such as 1,000 gallon covered jars are also made.

Most of the tableware produced in America is either whiteware or porcelain. The whiteware is porous and opaque although a good white, while the porcelain is a slightly bluer white, vitreous, impervious to liquids and partially translucent. Whiteware is divided into several classes dependent more or less upon the amount of porosity ranging all the way from four to ten per cent absorption. The best grade is known as "white granite."

Bodies of this type are produced from a mixture of kaolin, ball clay and ground feldspar and potter's flint or quartz. Feldspar melts when the body is heated and acts as a binder to cement the rest of the materials together. Vitreous porcelain not only contains slightly more of the feldspar or glass forming material but it is also burned to a higher temperature, so that the available feldspar becomes glassier and is able to bond better.

In the manufacture of whiteware the body, after forming, is first burned to about 1290°C. This is the bisque burn. The ware is then glazed and burned in the glost fire at about 1190°C. English practice is to use a glaze

that melts properly on the body at about 1120°C , thus making the English ware softer. The usual composition for the whiteware body is kaolin or china clay 35%, ball clay 15%, feldspar 15% and flint 35%.

The composition of American porcelain is about 45% of clays, 20% feldspar, 35% flint. Ware made from this body is burned to 1330°C in the bisque burn at which point it becomes very dense and vitreous. The glazing is done similar to whiteware.

The European practice is to burn the ware to a low bisque temperature, about 990°C , and then burn the glazed ware up to the vitrifying temperature about 1410°C . This produces a hard, vitreous, translucent body. The glaze is very hard, being free from the fluxes, such as lead and boric acid. It also has a fine opportunity to become soft and stick more closely to the bisque body.

True, hard-fire porcelain is not manufactured in America to any great extent; however, the chemical porcelain industry has grown enough since the War to make us independent of importation. Pyrometer Protection Tubes were made before the War by the Royal Porcelain Manufactory. This process was worked out in the States by the Ceramic Department at the Bureau of Standards at Pittsburgh, Pa., and the product is now being manufactured here by several firms.

Electrical porcelain usually has a composition about 50% kaolin and ball clay, 30% feldspar and 20% ground quartz or flint. This material is fired once only, the glaze being put on the green or dried unfired piece. This makes a very close union between the glaze and body. The burning temperature is approximately 1330°C . This body must be free from flaws of all sorts as it is subject to both mechanical and electrical strains at all times. Each piece of ware made must be tested before leaving the factory.

Porcelain for spark plugs must withstand high current at increased temperatures and this has led to the development of special porcelains. Internal combustion engines operate at temperatures as high as 950°C , while the ordinary porcelain becomes a conductor at about 400°C , making its use prohibitive. The Bureau of Standards and manufacturers have worked on this problem with considerable success and developed porcelains free from alkali fluxes and undissolved silica, both of which are objectionable, the former from a hot dielectric standpoint and the latter from a physical standpoint.

Plumbing supplies and sanitary ware must be made of vitreous porcelain; however, bath tubs and some of the larger pieces are made of a porous fire clay body, this being covered with a white vitreous coating and glaze.

Some very high grade work has been done in the United States in the manufacture of art pottery. Rookwood Pottery, made in Cincinnati, has made an international reputation having developed several distinct types of beautiful ware. The Onondaga Pottery Company of Syracuse,

N. Y., has done exceptional work in the development of high grade hotel china.

Lenox, Incorporated, of Trenton, N. J., is making a high grade Belleek ware. This is a beautiful vitreous translucent, cream colored ware which lends itself well to the use of golds and other types of decoration.

The Ohio Pottery Company of Zanesville, Ohio, should be complimented upon the excellent tableware it is making by the European method of burning, the first time to a low temperature and then glazing and maturing the ware at the final high temperature in the second burn. Many others are doing excellent work and the interest developed along lines of this sort is steadily growing.

Vitrified porcelain floor tile are being used extensively in all sorts of building while the use of glazed wall tile is increasing more and more. The necessity for increasing the amount of reflected light and the demand for more sanitary conditions have brought this about.

Hollow Ware.—Ware of this character is made out of the more common clays, such as shale, low grade fire clay, stoneware clays, etc. The sewer pipe business is well established and more or less dependent upon the growth of cities and villages. The development of scientific farming has brought about an increased demand for drain tile. Partition tile has done a great deal towards the development of certain types of construction and the growing demand will continue to call for an increase in its manufacture.

Architectural Terra Cotta and Tile.—The use of architectural terra cotta has developed in America until it is practically universally used on all large buildings. Its advantages over cut stone are many. It resists all sorts of weather conditions, and is fire-proof, strong, light and easily erected, as well as being much lower in cost. Its decorative possibilities are great as it can be modeled as desired and given any color or texture. The skyline of any city may be said to be a characteristic combination of steel and terra cotta. Terra cotta is also being used extensively for interior decoration.

Brick.—Common brick need not be mentioned here. Their use is too well-known.

Developments have been made in the face brick business that have brought about architectural treatments in construction which could not have been attempted a few years ago.

Paving blocks are used extensively for road construction and one of their chief advantages over other forms of construction is that of the prevention of skidding during wet weather. The success of a brick pavement depends upon the method of construction, great care being required to secure a proper concrete foundation.

Glass.—The glass industry is much more extensive than is usually realized. No matter what type of construction is used, any building must

have windows and this together with the increased demand due to modern factory construction has brought about a prosperous condition among glass manufacturers.

The development of and demand for automobiles has also enormously increased the demand for high grade glass and this demand is growing still more rapidly on account of the greater demand for closed cars. The demand for headlight lenses is also extensive.

A modern glass factory is probably as well developed and equipped as any type of factory. On account of the heavy production and expensive equipment required for any particular glass product, most plants are large and devote their entire energy to only one type of product. This trend towards quantity production has gradually eliminated the glass blower and replaced him with machinery.

Where glass used to be melted in small pots, holding a ton, it is now melted in large tanks as much as 90 to 120 feet long and 20 to 25 feet wide, the molten glass being three or more feet deep. These tanks are arranged so that the materials of which the glass is made are put in at one end of the tank, melted, and run down to the other end where the molten, fined glass is drawn off or gathered and molded or drawn into shape.

The old method of making window glass was to have a man gather a quantity on a hollow rod and blow it into a long cylinder. The size of the cylinder depended upon the gatherer who stood on a platform, holding the rod vertical with the glass on the lower end, then swinging the rod and glass like a pendulum as he blew. The glass, instead of forming like a soap-bubble, would lengthen out into a long egg-shaped ball which would be rolled against a flat surface and gradually shaped into a cylinder with rounded ends. When of proper size, this would be cooled and the ends cut off, leaving a sheet glass tube usually about eighteen inches in diameter and five feet long. While still warm this tube would be cut once lengthwise and placed on its side in a furnace on a large flat stone, the furnace being warm enough to slowly soften the glass. The operator instead of allowing the glass to collapse as it softened would see that the lateral cut was placed on top and would unroll the cylinder by means of a long pole so that as it became softer it would gradually flatten out into a sheet of glass the full length of the cylinder and the width of the circumference. At the right stage the operator would then take a flattening iron and iron out all rough parts of the glass. To do this it was essential that the flattening stone beneath be perfectly planed. The sheet of glass would then be pushed out on to a conveyor, which would carry it through a furnace which gradually cooled off so that the glass was cool and could be handled at the exit end where it would be cut to size, inspected and packed.

The modern method permits of the gathering of the glass in a continuous sheet, running it over rolls until cool enough to put it into the leer or cooling

and annealing tunnel, passing it through the same, sizing, inspecting and packing it. The increase in production, uniformity of product, opportunities for control, etc., are obvious.

In the manufacture of hollow ware, the Owens machine and similar equipment have brought about developments that were unthought of a few years ago.

Art glass has been developed to a high degree and is worthy of mention. The Tiffany Favril glass is well-known by everyone. The artistic side of the lighting fixture glass ware industry has also been brought to a point where interior decoration schemes can be carried out with the lights as well as the hangings, and at a price that makes it possible in reasonably priced buildings.

Enameled Steel and Iron.—We are all familiar with the extent to which these products are used, at least so far as they are used in plumbing supplies and cooking ware manufacture; however, a good many of us do not realize the extent to which the enamel is used in the manufacture of gas stoves, refrigerator linings, soda fountain and restaurant equipment, kitchen table tops, steel thermos bottle linings, street signs, automobile license plates, etc. These are all things we see every day. Among the things we do not see that are enameled are the vats, tanks, pressure cookers and other equipment of this sort used in the manufacture of many products such as soft drinks, candies, toilet goods, etc. The development of chemical enameled ware has been perfected after extensive research work by the enamellers. Special enamels suitable for electrical insulation purposes have recently been developed. These are being used in resistors, electrical heaters and in similar equipment and no doubt the uses will be much greater as time goes on.

The development of an enamel of this character for automobile bodies would be a development worth consideration from the standpoint of the owner but the problems to be met by the manufacturer would be tremendous. The present baked enamels used in automobile work are put on at temperatures below red heat, but enamels of the type used in fused enamel work require temperatures well above red heat.

The enameling of jewelry, watch dials, etc., is an industry of considerable size.

The process of enameling iron appears to be very simple but requires great care, attention to detail and experience. The previously cleaned steel or iron piece which it is desired to enamel is heated red hot, drawn from the furnace, coated with a layer of finely ground glass or enamel, again inserted into the furnace until the glass has smoothed out, and then withdrawn and cooled. Sometimes the enamel coat is put on the piece before heating and usually several coats are applied. The price of a cooking utensil will vary with the number of coats of enamel, the color, etc. The kind of metal to

use, different kinds of enamel, as slush or first coat, and second coat, and proper temperature for best fusing the enamel to the iron without over-burning, are all important points. The thermal coefficient of expansion of the enamel must be the same as that of the iron to prevent its chipping off, fish scaling, when subjected to changes in temperature or to impact.

Abrasives.—Most abrasives are artificial and manufactured by fusing or sintering raw materials together in an electric arc. These synthetic materials are later crushed and bonded together and formed into useful articles. Alundum is made by driving off the silica from bauxite leaving the fused alumina. Silicon carbide is made by chemically combining coke dust and sand in an electric arc.

These and similar products are ground to the proper grain size. This grain size depends upon the character of the finished product desired. Coarse grained and fine grained grinding wheels, of course, would be made of grains best suited for the particular purpose. The grains are mixed with ceramic bonds, usually clays, feldspars and the like and tamped into molds of the desired shape. When dry the wheels are placed in kilns very similar to a down-draft brick kiln and burned to a temperature sufficient to fuse the bond and hold the grains together. This temperature is around 1200°C but varies with the type of bond, character of grain, etc.

Refractories.—Refractories are used in practically all branches of manufacture, particularly in the metallurgical arts, clay, glass and cement industries as well as in the generation of steam. The most important types of refractories are clay, silica and magnesite.

(1) *Clay Refractories.*—Refractory clays are generally divided into three classes, *i. e.*, No. 1, No. 2, and No. 3, the grade depending upon the degree of refractoriness. Ware made from these clays will be classed approximately the same as the clays.

Kaolinite, the purest form of clay, has a melting point of approximately 1755°C . Usually clays are contaminated with some impurities which lower the melting point. On the other hand some clays contain more alumina than the theoretical amount for kaolinite. These usually contain some bauxite and they may raise the melting point up as high as 1800°C . Usually clays melting above 1685°C are classed as number one, those melting below this but above 1635°C as number two and those below that as number three.

Fire clays are also divided according to their silica content. Siliceous clays have a content of over 75% SiO_2 and are not as refractory as the less siliceous clays but have other good qualities, being less subject to shrinkage after being made into brick and subjected to long usage. They will stand up in use to temperatures approaching their fusion point while the lower silica content brick cannot be carried to temperatures within 150°C below their deformation point.

(2) *Silica Refractories*.—These are principally produced from ground quartzite being bonded with about 2% of lime paste. In manufacturing, products of this character must be burned to 1500°C. During the burning the quartz is transformed to cristobalite, an intermediate crystalline modification of silica. Considerable expansion takes place during this burning. With continued use at high temperatures part of the cristobalite transforms into tridymite. Silica brick do not soften much below their fusing point and can be used with safety under load at 1600°C. Unfortunately they do not stand up well under conditions of sudden heating and cooling, particularly if cooled to under 600°C.

(3) *Aluminous Refractories*.—These are usually made up of mixtures of clay and bauxite and have been found capable, in some instances, of replacing magnesite brick. Bauxites melt at around 1800 to 1820°C but have extremely high shrinkage making it necessary to previously calcine the material to have a good product.

(4) *Magnesia Refractories*.—The melting point of pure magnesia is about 2800°C. The pure material shrinks about 50% so that it is necessary to use grades containing iron or some other flux in order to produce products of the proper density. Brick made of magnesite are very valuable on account of their basic nature and high heat resistant qualities.

(5) *Other Refractories*.—Silicon carbide refractories have proved very useful under special conditions. This material, although it oxidizes readily particularly at lower temperatures, is capable of standing up under load at higher temperatures than most other refractories. It also has a high thermal conductivity which makes it very useful for muffles and other types of construction where heat transfer is requisite.

Zircon or zirconium silicate and zirconia have also proved of value as refractories at high temperatures under special conditions but the manufacture has not been developed to any great degree.

Refractories for glass house use have been well developed and play an important part in the manufacture of glass.

Progress of Ceramic Work during the War

Like all other industries, the ceramic industry found the lack of importation was a serious handicap during the War. This was also realized by some consumers of ceramic products when they were unable to buy abroad. As in other cases this lack created a demand and willingness to pay on the part of the consumer that inspired the manufacturers to develop the old products or create substitutes. The necessities of the War also inspired those interested in the technical side of the questions and brought about a coöperation that, at least in the ceramic industries, bids well to continue.

Optical Glass.—Optical glass, the total supply of which had been

manufactured abroad, particularly in Germany, was probably the most sought for ceramic product. The study of the melting of optical glass was begun by the Bureau of Standards on a laboratory scale in 1914 and the manufacture of it as early as 1912 by the Bausch and Lomb Optical Company of Rochester, New York; in 1915 by the Keuffel and Esser Company, Hoboken, New Jersey, and the Pittsburgh Plate Glass Company, Pittsburgh, Pa., and in 1916 by the Spencer Lens Company of Buffalo, New York. The Bureau of Standards built a small glass plate in Pittsburgh in 1917 and later a larger one in Washington.

The Geophysical Laboratory of the Carnegie Institution of Washington, D. C., was placed in charge of optical glass production under the War Industries Board and its staff coöperated in the management of three of the plants which produced the bulk of the glass manufactured. This Institution did most valuable work in insisting upon the use of extremely pure raw materials, in the testing of the finished glass, the annealing process and other incident problems.

The Bureau of Standards contributed the development of special glass pots, made from porcelain-like bodies, rapid testing methods for the examination of the glass and an elaborate study of the changes occurring on annealing. Its Washington plant is still on a productive basis and makes optical glass for the Navy.

It might be said therefore that we have succeeded in establishing an optical glass industry in this country, which is in position to supply all of our peace and war needs.

All of the improvements made in the optical work benefitted the commercial glass manufacturers in indirect ways, and as a result they have, in many instances, made changes in processes. Special glass, which was largely imported, is now manufactured rather extensively at home.

Chemical Glassware.—Chemical glassware, which had previously been imported is now being made in the States on a scale large enough to meet our requirements. The Corning Glass Works has developed a line of Pyrex chemical ware that is superior to anything previously imported.

Chemical Porcelain.—Chemical Porcelain is now being manufactured at home and it is hoped this industry will continue to thrive. The quality of the American ware is satisfactory but the cost of manufacture is necessarily high and, like the pottery trade, dependent upon reasonable protection.

Refractory Porcelain.—Refractory porcelain, particularly pyrometer protection tubes, was not available shortly after the War began. The actual value of this product is not great, but the lack of it was keenly felt. At least four concerns are now manufacturing these products with considerable success. The original tubes were developed by the Bureau of Standards.

Spark Plugs.—The demand for high grade porcelain cores for spark plugs has been largely caused by the severe use to which they have been subjected in airplanes and in later types of engines where high temperatures and pressures are required. Here, Bleininger and his associates of the Bureau of Standards were able to produce a better porcelain which was rapidly taken up by some of the more progressive manufacturers and produced on a commercial scale. It was found that the alkalies and free quartz were objectionable and the use of substitutes necessitated the use of much higher temperatures than are commonly used. This again compelled the use of special refractories for the saggars and the kiln linings for which pure silicon carbide is largely employed.

Abrasives.—There was undoubtedly considerable improvement made in abrasives during the War but perhaps the greatest benefit was the development of uses for abrasives, particularly grinding wheels. A great deal of machine shop work is now being done with grinding wheels that was previously done in other ways at a higher cost or less efficiently.

Development of Better Refractories.—Improvements were made more or less indirectly but nevertheless the results will always be felt. The demand for increased production and greater service particularly in power plants brought about a demand for higher grade refractories or improvement in design requiring special shapes and this has helped to educate the consumer to the necessity for high grade work. The experiences of the Carnegie Steel Company and other large steel companies brought about changes that have helped to make improvements.

Enameled Iron.—Here again, although there have been great improvements in quality of product, the greatest benefit has resulted from the education of the consumer and the development of new uses for the product.

Chemical Stoneware.—This industry was well-developed before the War but it should be mentioned here on account of the extreme importance of the product for the manufacture of chemicals, powder and other materials so necessary in War times. It is unfortunate that the demand for products of this character are not as great in times of peace.

Graphite Crucibles.—The inability to secure sufficient Ceylon graphite caused distress among the crucible manufacturers and still more serious was the lack of bond clay, formerly imported from Germany, which was missing entirely. The properties of the German clays and their corresponding types of American bond clays were studied by the Bureau of Standards but the whole question of graphite and clay was taken up by the Bureau of Mines which did valuable and extensive work in this connection. Through careful laboratory and shop tests it proved that graphite crucibles can be successfully made from American materials. The contribution of the Bureau of Mines on graphite crucibles represents the most complete work ever done on this subject.

The Bureau of Mines also did much work in searching for domestic raw materials to replace those previously imported. Among other activities it undertook an elaborate survey of the white clay resources east of the Mississippi.

Ceramic Schools

The Ceramic Department at Ohio State University was organized over twenty-five years ago with Prof. Edward Orton, Jr., as director. Rutgers College, at its last commencement and at the dedication of its new ceramic building, honored him with a Doctor's degree. Doctor Orton has probably done more than any other man to further the interests of ceramics, in America and indirectly throughout the world.

Prof. Charles F. Binns has also been very active for many years and he will be prominently mentioned in the history of the ceramic art in America particularly in connection with the development of the technical and artistic aspects of the industry.

The following is a brief outline of the history of ceramic schools:

TABLE I				
Name of school	Ceramic department founded	Founded through efforts of	Original department head	Present department head
Ohio State University	1894	Prof. Edward Orton, Jr. and Ohio Clay Operators	Prof. Edward Orton, Jr.	Prof. A. S. Watts
New York State School of Clay Working and Ceramics	1900	Pres. B. C. Davis Hon. John J. Merrill	Prof. Charles F. Binns	Prof. Charles F. Binns
Rutgers College and the State University of New Jersey	1902	New Jersey Clay Workers	Prof. Cullen W. Parmelee	Prof. George H. Brown
University of Illinois	1905	Prof. Charles W. Rolfe	Prof. Ross C. Purdy	Prof. Cullen W. Parmelee
Iowa State College of Agriculture and Mechanical Arts.	1906	Clay and Cement Manufacturers and Users of Iowa	Prof. Ira A. Williams	Prof. Paul E. Cox
University of Washington	1918	Dean Roberts	Prof. Ira A. Williams	Prof. Hewitt Wilson
University of Saskatchewan, Canada	1921	Prof. T. Thorwaldson	Prof. W. G. Worcester	Prof. W. G. Worcester

Other Professors and Instructors not listed above: Ohio State University: Professors R. C. Purdy, A. V. Bleining, H. F. Staley, C. B. Harrop, Hewitt Wilson; Assistants or Instructors: F. H. Riddle, J. M. Knote, W. G. Worcester, Jas. T. Robson.

New York State School of Clay Working and Ceramics: Miss L. W. Tourtellotte, E. S. Babcock, Miss Adelaide M. Blanchard, Herbert K. Cummings, Miss M. Elsie

Binns, G. K. Daghljan, A. R. Heubach, E. T. Montgomery, George A. Bole, Joseph B. Shaw, Miss Katherine Nelson, Miss Marion L. Fosdick.

Rutgers College: See Table.

University of Illinois: Professors R. C. Purdy, A. V. Bleining, R. T. Stull, R. K. Hursh, E. W. Washburn.

Iowa State College of Agriculture and Mechanic Arts: Professors Amos Potts, Homer F. Staley, S. L. Galpin, O. J. Whittemore.

University of Washington, Seattle, Washington: See Table.

University of Saskatchewan, Saskatoon, Sas., Canada: See Table.

Relations between Ceramic Interests

By ceramic interests is meant those who are not only directly interested in the production of ceramic products but also those who are directly or indirectly connected for some other reason. Among these would be included the Trade Associations, Government Bureaus, Research Laboratories, Technical Societies and indirectly the ceramic schools.

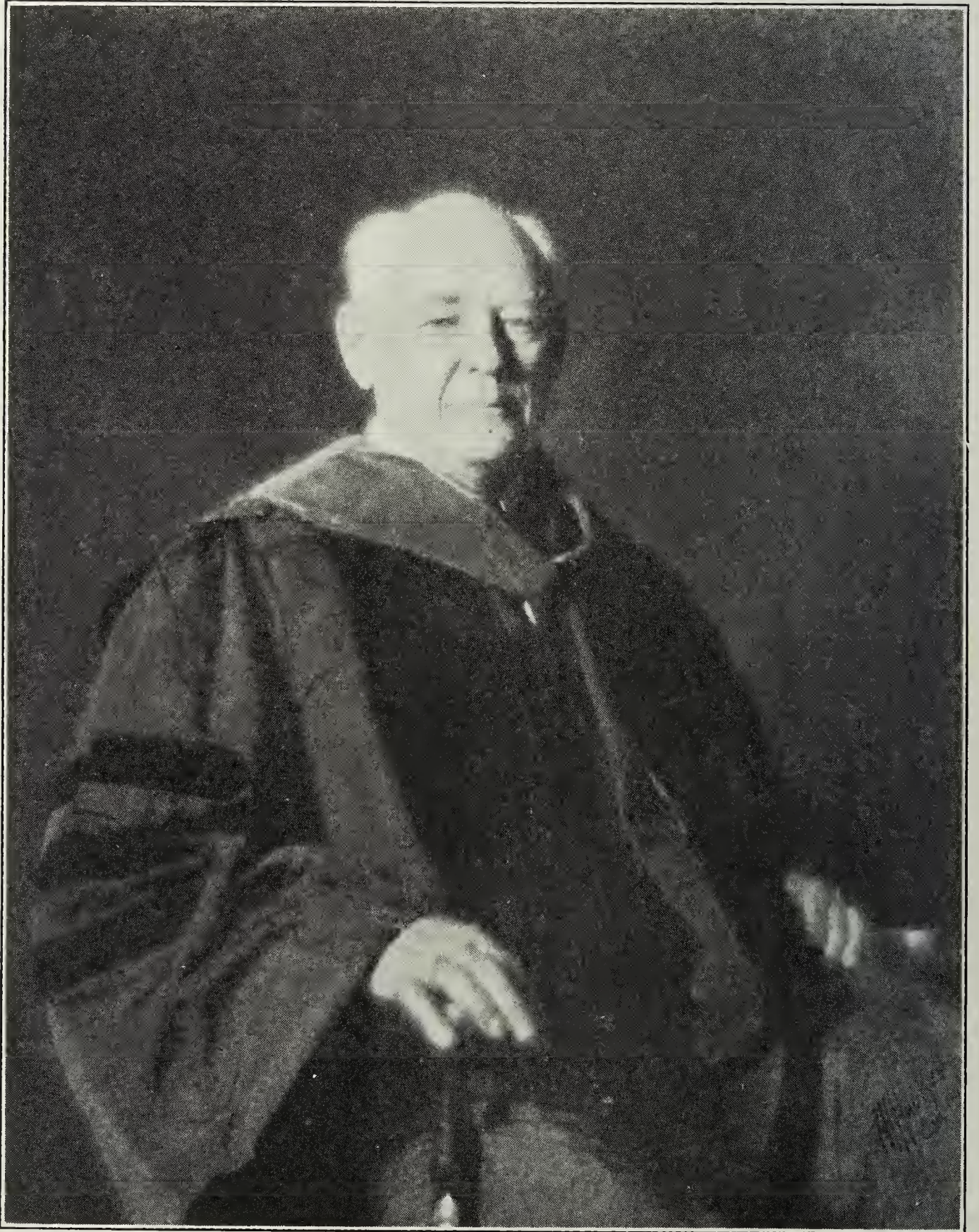
The necessities which arose during the War induced a coöperation between these interests that has made each one realize how little he can accomplish without the coöperation of the others and how much can be accomplished by this coöperation. Associations are maintained by the Potters, Electrical Porcelain Manufacturers, Tile Manufacturers, Sewer Pipe Manufacturers, Common Brick Manufacturers, Face Brick Manufacturers, Fire Brick or Refractories Manufacturers, Paving Brick Manufacturers, Several Glass Manufacturers' Associations, Enameled Iron Manufacturers, Grinding Wheel Manufacturers. Government Bureaus which are directly interested in ceramics are the Bureau of Standards, the Bureau of Mines and the United States Geological Survey. Both Bureaus have extensive equipment and specially trained technical staffs interested directly in ceramics. The Bureau of Mines deals directly with the raw materials, source, etc., while the Bureau of Standards is more interested in the product, method of testing, and development of standards.

Several of the Trade Associations have arrangements with research laboratories and have investigators working in these laboratories under the direction of joint committees made up of members on the staffs of the associations and laboratories. This is also being done by some of the manufacturers, particularly where they do not have proper facilities for carrying the work on themselves or else when they desire the work to be carried on under the direction of some specialists who are connected with some available laboratory.

All of the above associations, with the possible exception of two or three, are carrying on research work in the above way. The Refractories Association has undertaken rather extensive work which is being carried on at the Mellon Institute of Industrial Research in Pittsburgh, Pa. This Institute has directed research for several ceramic manufacturers and is to

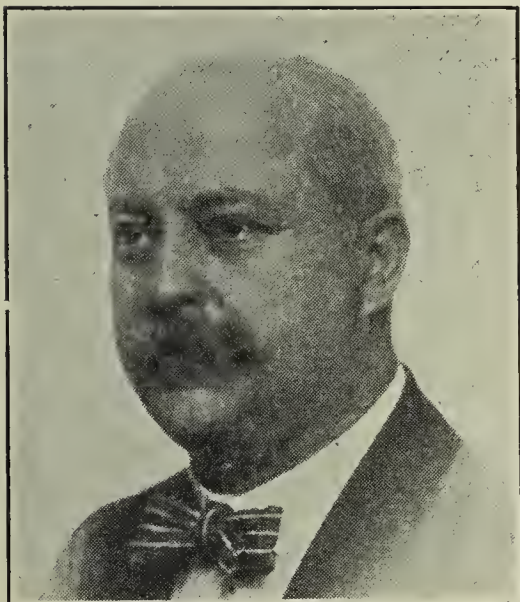
be complimented for the value of these investigations. The various brick manufacturers have appropriated a large sum of money and they, together with the Bureau of Standards, Bureau of Mines, a couple of the Ceramic Schools and representatives of the AMERICAN CERAMIC SOCIETY and National Research Council, have undertaken some extensive work. An important part of this work is that of efficiency in burning. The Bureau of Mines has equipped a car similar in character to those they use in mine rescue work and sends it right to the factory where investigation work is to be carried on so that the crew of technically trained ceramic men can be on duty at all times and also have all the apparatus necessary to carry on the work properly.

Industrial research being recognized as an absolute necessity, large corporations are appropriating hundreds of thousands of dollars annually in support of their extensively organized private laboratories. It would seem that the importance of industrial research laboratories was so evident that no manufacturer would be without one. The possibilities of economics in process, and sure improvements in products in the application of scientific discoveries and by the application of process control methods are very great; in fact it is essential that work of this character be undertaken by those who are to continue with any degree of success.



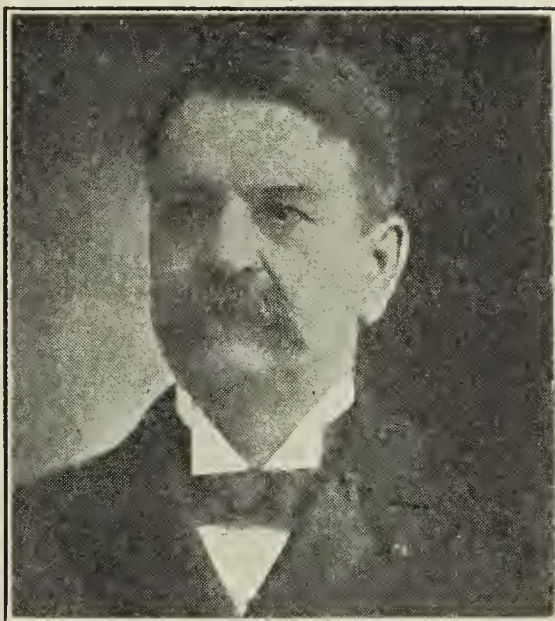
COLONEL EDWARD ORTON, JR.

OUR UNIVERSITIES



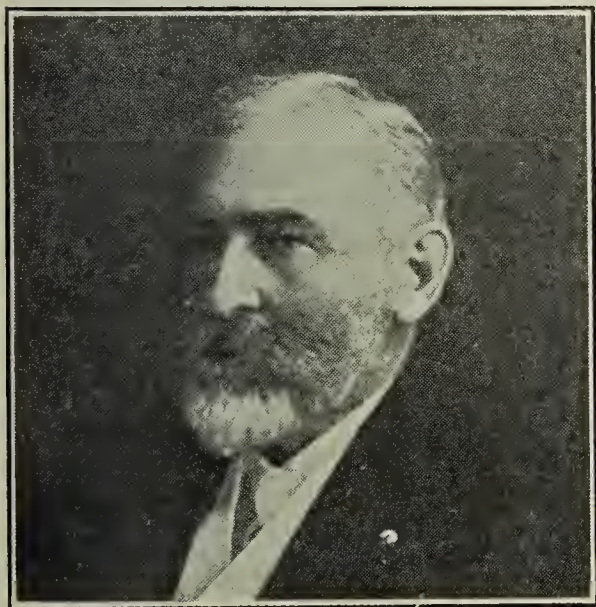
THEO. A. RANDALL

Theodore A. Randall of Indianapolis, Ind., has been secretary of the National Brick Manufacturers' Association, since its organization in 1886. He has served continuously, which is a world record.



D. V. PURINGTON

D. V. Purington was president of the National Brick Manufacturers' Association.



CHARLES A. BLOOMFIELD

Charles A. Bloomfield was president of the National Brick Manufacturers' Association, 1912-13. He was first president of the New Jersey Clay Workers' Association and Eastern Section of the AMERICAN CERAMIC SOCIETY, and took the lead in organizing and managing the movement that resulted in the establishment of the Ceramic Department at Rutgers College.

To Professor Edward Orton, Jr., E.M., D.Sc., belongs the credit for establishing the first collegiate department in Ceramic Engineering. He obtained the solid support of the members of the National Brick Manufacturers' Association, and was fortunate in having the active personal support of D. V. Purington, W. D. Richardson, W. D. Gates, Charles A. Bloomfield, and T. A. Randall, representing national interests and several of the potters and brick manufacturers of Ohio. With the support of these men, Prof. Orton overcame the opposition of the University authorities and obtained the passage of the necessary bill through the Ohio legislature.

Thus was started in 1895 the world's first collegiate course in Ceramics. Quickly following was the founding of the AMERICAN CERAMIC SOCIETY and the establishment of collegiate ceramic departments in other universities.

On the occasion of the dedication of

the new and well appointed ceramic building at Rutgers College last June, the honorary degree of Doctor of Science was bestowed upon Professor Orton in recognition of the services he had rendered to ceramic crafts of the world, in addition to similar constructive organization service in other fields, notably geology, and as Dean of the College of Engineering. His country had already decorated him with a Distinguished Service Medal and had promoted him to the rank of Colonel for the self-same organization success and personal inspiration to his fellows by which he had so singularly distinguished himself in ceramics and as Dean of a college.

To the pupils who have had direct contact with Professor Orton in lecture room and laboratory at the Ohio State University has been given the larger share of his inspired leadership. In recognition of this, they have presented to the Ceramic Department at Rutgers College a full-size portrait of him in his doctorate robes and colors from Rutgers.

Recognizing that the several ceramic schools from the earliest period have been largely responsible for the technically trained ceramists and for the fund of ceramic knowledge on which the present day productive scheme of coöperation and coördination in ceramic research is built, brief summary accounts of the collegiate departments are here given.

DEPARTMENT OF CERAMIC ENGINEERING, THE OHIO STATE UNIVERSITY

BY ARTHUR S. WATTS

The Ceramic Engineering Department of The Ohio State University was established by act of the Ohio State Legislature on April 20, 1894.

The Department was conceived by Edward Orton, Jr., E.M., and established largely through his efforts and with the support of a few of the clayworkers of Ohio. It was the first school of its kind in the United States, and, to the best of our knowledge, in the world. The Department opened in September, 1895, with fifteen students in a two-year course, known as "Clayworking and Ceramics" for which no degree was granted. In 1896 two students enrolled in a regular four-year course, the first graduate being Walter M. Fickes "1900," who received the degree of "E.M. in Cer." The degree conferred was changed in 1908 to "Cer.E.," and again in 1915 to "B.Cer.E."

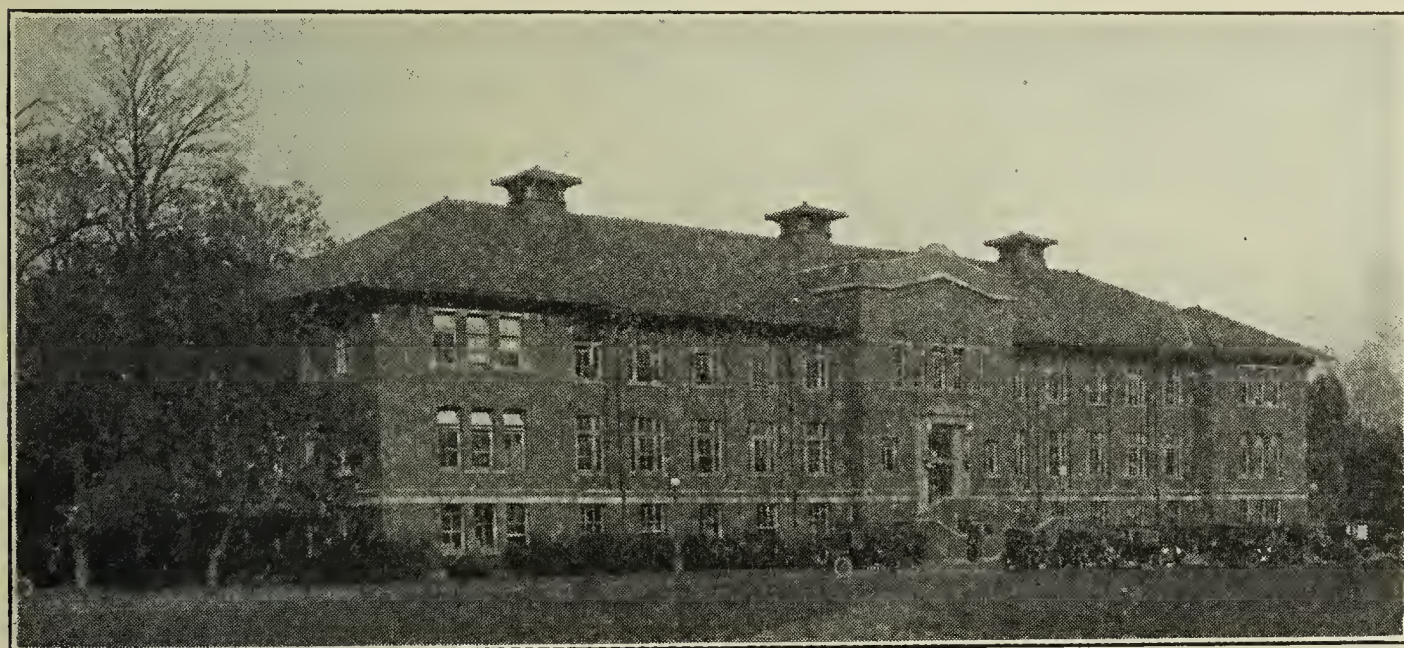
The Department was located originally in Orton Hall with the Department of Geology, being transferred in 1906 to Lord Hall, which was erected to accommodate the Department of Mines, Metallurgy and Ceramics.

The original four-year course consisted of approximately fifty per cent fundamentals, 25% advanced general engineering and 25% fundamental and advanced ceramics. Individual courses in the curriculum have been changed but always in kind and the course at present consists of forty-

five per cent fundamentals, including cultural, twenty-five per cent advanced engineering and thirty per cent ceramic engineering.

The most important additions to the curriculum within the Ceramic Engineering Department were the application of Physical Chemistry to Ceramics, introduced in 1910, the courses in Ceramic Machinery and Factory Design, introduced in 1911, the course in Refractories and Furnaces, introduced in 1918, and special post graduate courses in Ceramics, introduced in 1917. The most notable additions to the curriculum from outside the Department are the courses in fundamental Physical Chemistry, in Fuels, in Mineralogy and in Pyrometer Construction and Operation.

The object of the curriculum is strictly professional. It does not give nor pretend to give manual skill in any of the practical arts of modeling,



Lord Hall, Ohio State University.

forming or decorating. It is a study of the technology—the engineering, which is used in the clay and allied silicate industries.

The development of ceramics has made it impossible to cover the field in more than a general manner in the time available in a four year course.

The distribution of ceramic graduates in the different branches of the industry is as follows:

Of 166 graduates, 32% are employed in crude ceramics, 14% in architectural ceramics, 20% in fine ceramics, 12½% in refractories, 8% in cement, glass and metal enamels, 8% in teaching or government research, and 5½% are not following ceramics.

The enrollment of students in the Department has never been large, the total of sophomores, juniors and seniors never having exceeded 55, and the largest class graduated being 18 in 1909. The present enrollment

is 49, with 12 seniors. Freshmen cannot be counted since they take no work in the Department.

The personnel of the Department has been as follows:

Professor Edward Orton, Jr., Head of Department, 1895 to 1914, incl.

Professor Arthur S. Watts, Professor 1913-15, Head of Department, 1915 to date.

W. L. Evans, Assistant in Ceramics, 1895 and 1896.

Theodore Griffin, Assistant in Ceramics, 1897.

A. V. Bleining, Laboratory Assistant in Ceramics, 1898 and 1899; Assistant in Ceramics, 1901, '02, '03, and '04; Assistant Professor, 1905; Associate Professor, 1906.

S. V. Peppel, Assistant in Ceramics, 1901.

R. C. Purdy, Assistant in Ceramics, 1903, '04, and '05; Assistant Professor, 1907; Associate Professor, 1908, '09, and '10; Professor, 1911; Acting Head of Department, 1909.

F. H. Riddle, Laboratory Assistant, 1906.

W. G. Worcester, Laboratory Assistant, 1907, '08, and '09; Instructor, 1910.

J. H. Knote, Laboratory Assistant, 1907.

H. F. Staley, Associate Professor, 1910; Professor, 1911.

C. B. Harrop, Assistant Professor, 1911 to date.

A. P. Potts, Assistant in Ceramic Engineering, 1911.

F. K. Pence, Professor, 1912.

J. C. Lysatt, Mechanician, 1912 to date.

Hewitt Wilson, Assistant Professor, 1917 and '18.

J. T. Robson, Instructor, 1919 to date.

NEW YORK STATE SCHOOL OF CLAY-WORKING AND CERAMICS

BY CHARLES F. BINNS

The School of Clay-Working and Ceramics at Alfred, N. Y., was founded by an act of the Legislature of the State of New York in 1900. This act appropriated \$15,000 for the building and equipment and \$5,000 for the expenses of the first year. Incredible as it may seem, a good sized building was erected for \$11,800 and although it was built of brick it was a mere shell. The partitions and stairways were all of wood. It had no heating system or plumbing. Gas stoves were borrowed from the University and by dint of strict economy the equipment was assembled. Appropriations were not then itemized, a fact which rendered this possible.

At that time the chief thought which ruled ceramic education was brick. The solons at Albany had to be told that the raw materials of the

State should be more fully utilized, that better building material should be produced, and that, therefore, the school should be established. It was forgotten, or perhaps had not then been announced, that the chief raw material lies in terms of human beings and that the proper product of all education is men and women.

In pursuance of the brick idea the basement of the school was equipped as a brick plant. Drypan, pug mill and augur machine were purchased, the pug mill being elevated in proper style upon a huge platform up to which the perspiring students were expected to shovel the clay. Probably a mechanical elevator would have been put in if there had been money enough. The pug mill with its platform has long since disappeared and a wet pan has been added. The power was and is furnished by a 36-H. P. Otto gas engine.



New York State School of Clay-Working and Ceramics.

Not to neglect the study of pottery, a slipmaking plant, a potter's wheel and a jigger with pull-down were installed, together with mold making and sagger making appliances and tools.

A chimney stack about 60 feet high was built and at the base of this a kiln, patterned after the kiln at Ohio State. A wooden shed protected the kiln but was not connected with the building so that everything to be fired had to be carried across the open. In 1915 a considerable addition was made to the building consisting of a fireproof wing to house the kilns and furnaces, with a chemical laboratory and a large general workshop.

From the beginning the director planned to include some instruction in art in the curriculum although, for the reason already stated, this was not emphasized. Nevertheless, Miss Alice Upton, a graduate of Pratt Institute, Brooklyn, was engaged as instructor in drawing and modeling and for some years she, and her successors, with the director, constituted the entire teaching staff. Ten years elapsed before it became possible, as it had long been desirable, to divide the art work, appointing an associate professor of modeling and another of drawing and design. Not until 1912 were the funds made sufficient to provide an assistant in technology, the director up to that time having taught this subject single-



New York State School of Ceramics.

handed. At the present time the following persons are on the faculty:

Charles F. Binns, Director

J. B. Shaw, Professor of Ceramic Engineering

Marion L. Fosdick, Professor of Modeling

Arthur H. Radasch, Professor of Chemistry

Erna Sonne, Associate Professor of Design

George Blumenthal, Jr., Instructor.

There are several student assistants, and in addition the faculty of Alfred University gives instruction in all general collegiate subjects.

The registration of students progressed uniformly, if slowly. Beginning with three or four it mounted steadily to about forty and for several years

remained almost stationary but at the close of the War there was a great increase until in 1922 there were more than a hundred.

This school standing alone in the attention given to art training as applied to ceramics has been applied to for teachers by practically all the institutions where the designing and making of pottery is taught. Most of those who take this course are young women although a few men have graduated in applied art with conspicuous success.

The majority of the men prefer the course in ceramic engineering and these constitute about seventy per cent of the student body. There has been no difficulty as yet in the graduates finding attractive positions and a number of them have attained some importance in their profession.

ALFRED, N. Y.

THE CERAMIC DEPARTMENT AT RUTGERS COLLEGE AND THE STATE UNIVERSITY OF NEW JERSEY

BY GEORGE H. BROWN

Rutgers College, founded in 1766, first gave service to the ceramic industries of New Jersey through a vice-president of the College, the late Dr. George H. Cook. His report on the New Jersey clays,¹ which he investigated as State Geologist, together with Dr. J. C. Smock, also of Rutgers, is only one example of his achievements in this field of work. Situated in the center of the Raritan River clay-working district and in close proximity to the ceramic industrial centers of Perth Amboy and Trenton, Rutgers College was the logical place for the establishment of a Ceramic Department.

In the year 1901, a group of men representing some of the ceramic plants in the State, under the leadership of Mr. Charles A. Bloomfield, made an effort to secure legislation toward the establishment of a Ceramics Department at Rutgers College. The first bill was defeated but its sponsors were not discouraged and when the bill was again introduced in the Legislature in 1902, it passed with but one dissenting vote (Laws, Session of 1902, Chapter 17). The initial appropriation for building and equipment was \$12,000, with an additional \$2,500 for maintenance during the year 1903.

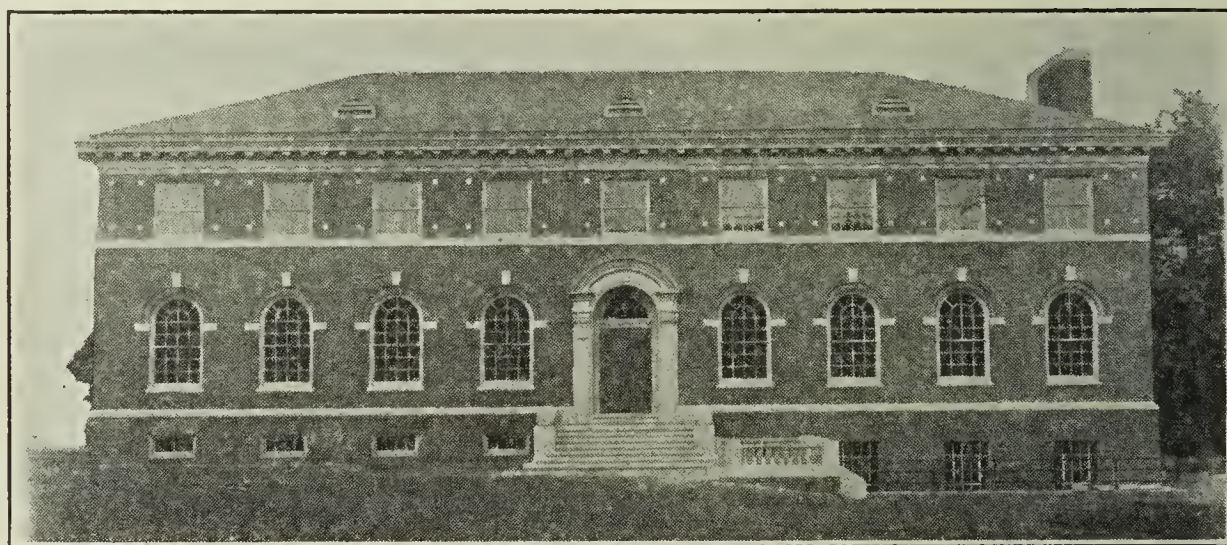
Having available the appropriation, the next problem was to secure a suitable building for the housing of the new Ceramics Department. The College buildings were either taxed to capacity or else unsuited for the purpose in view. It was finally decided to use a two-story brick stable which was the property of the College. The stable had six small rooms with a total floor space of about 1600 square feet. This served as

¹ Report on Clay Deposits of Woodbridge, South Amboy and other places in New Jersey. 1878.

a nucleus and a one story brick addition was built on to complete the first Ceramics Building at Rutgers College.

The machinery room, store room, drying and kiln rooms were located on the first floor. On the second floor there was a class room, combined library and museum, together with the director's office and laboratory. The ceilings in all these rooms were very old fashioned and low and it was found necessary to light and ventilate the laboratory by means of a glass skylight. The rooms were renovated, cases were built in for displaying specimens, etc., and all available space was utilized to the best possible advantage. The usual line of clay-working machinery was installed, together with one coal-fired kiln.

Two courses of study were arranged—the regular course, covering a period of four years, and a short course of two years.



Neilson Campus elevation, Ceramics Building, Rutgers.

The new Ceramics Department was organized under the direction of Dr. W. S. Myers, at that time head of the Chemistry Department at Rutgers College. Professor Cullen W. Parmelee took charge of the Department in 1903 and continued at its head until he left to serve as Professor of Ceramic Engineering at the University of Illinois in 1916. To Professor Parmelee is due great credit for the difficult organization work necessary to the establishment of the new Ceramics Department.

Professor Parmelee was succeeded by Professor George H. Brown, who came from the Bureau of Standards, Pittsburgh, Pa., to accept the directorship of the Department. Messrs. H. W. Moore (Precision Grinding Wheel Co., Philadelphia, Pa.); G. A. Williams (Atlantic Terra Cotta Co., Perth Amboy, N. J.); C. F. Geiger (Carborundum Co., Perth Amboy, N. J.); F. S. Thompson (Freehold, N. J.) and E. C. Hill (Conkling-Armstrong Terra Cotta Co., Philadelphia, Pa.), served on the teaching and research staffs at some time during this period.

After eighteen years of service to the industry, the Ceramics Depart-

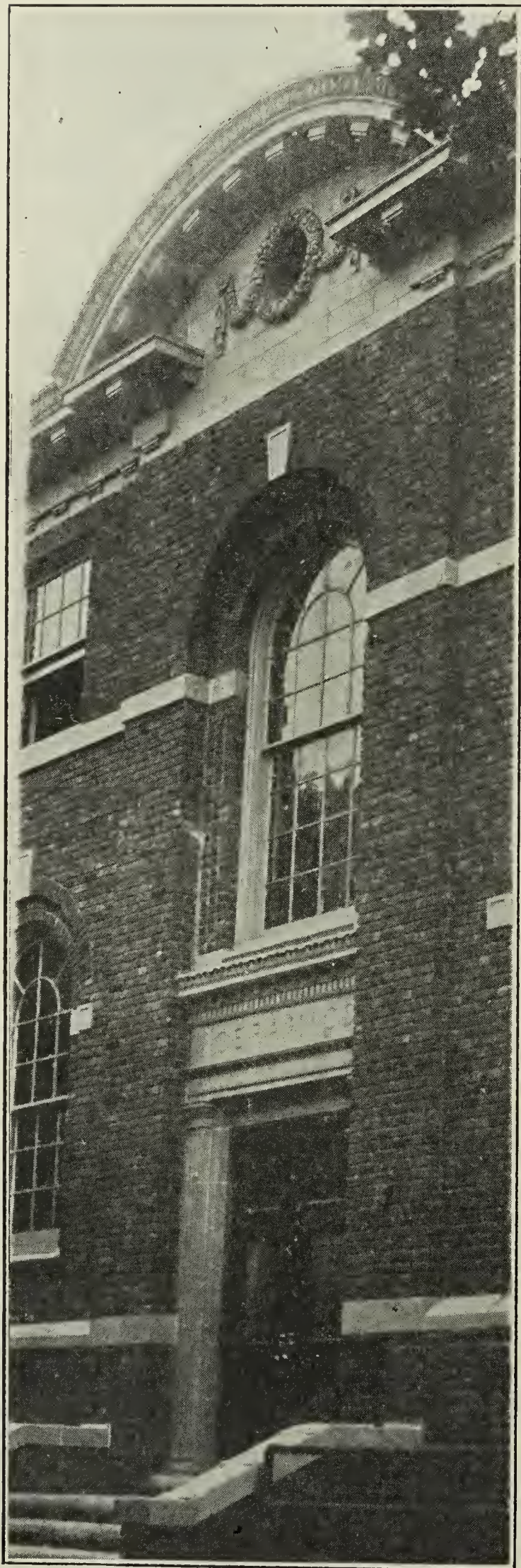
ment completely outgrew its old quarters. Realizing this fact, the New Jersey Clay Workers' Association in 1919 launched a campaign for a new building which would be more in keeping with the importance of the industry in the State. State Senator Thomas Brown of Middlesex County, sponsored the project and gave it his whole-hearted support. Representatives of practically every ceramic concern in the State lent their aid to the measure through personal letters to their legislators, etc. After an interesting series of hearings before committees of the legislature and the Governor, Senate Bill No. 17, appropriating \$100,000 for the erection and equipment of a new Ceramics Building at Rutgers College and the State University of New Jersey, became a law, and the necessary sum was included as an item in the annual appropriation bill.

An excellent site on Neilson Campus was assigned for the building. A prize competition was held under the direction of the Eastern Terra Cotta Manufacturers' Association for the purpose of securing a suitable design for the proposed building. Many helpful suggestions were included in the prize winning drawings, which were submitted to the architect for his consideration in drawing up the final plans. The building is of Colonial design, the architecture conforming with that of the other buildings on the Campus. Under the direction of the State Division of Architecture and Construction, contracts were awarded for the erection of the new building. Ground was broken during the summer of 1921 and the completed building was dedicated on Commencement Day, June 13th, 1922.

The new building is located on Neilson Campus, adjacent to the Engineering and Chemistry buildings. It is a far cry from the stable of 1903 to the modern and commodious structure, 45 x 102 ft., consisting of two floors and basement, with a total of 29 rooms. The building is constructed almost entirely of burned clay products and is representative of every line of ceramic manufacture in New Jersey. The handsome terra cotta exterior finish, tiled floors and corridors, sanitary wares—to mention only a few—are splendid examples of the high excellency of ceramic products manufactured in New Jersey. The building is a combination of the artistic and the practical.



Terra cotta entrance, Assembly Room, Ceramics Building, Rutgers.



George Street entrance and façade, Ceramics Building, Rutgers

The building is completely equipped for instruction and research work in ceramics. Modern machinery and equipment have been installed, including a number of new test kilns and furnaces. A chemical laboratory has been provided, filling a long-felt want in the Department.

The Department of Ceramics is under the direction of Professor George H. Brown (Cer.Eng., O. S. U. '08); Clifford C. Clarke (B.S., Colgate, M.Sc., Rutgers) and Harold T. Coss (B.S., Illinois) are serving as assistants.

The enrollment in the Ceramics Department is 25—a threefold increase over its largest enrollment heretofore. The young men of the State are becoming more and more interested in ceramics and there is every indication of a material increase in enrollment in the near future. The men enrolled in the course at the present time are bright and energetic students who are taking a real interest in ceramics.

The part played by the New Jersey Clay Workers' Association and Eastern Section of the AMERICAN CERAMIC SOCIETY in the culmination of this worthy project cannot be emphasized too strongly. From the start the Ceramics Department at Rutgers has had their whole-hearted support, both spiritually and financially. Their generosity in supplying large quantities of ceramic products and liberal sums of money has alone made possible the handsome structure which the Department now oc-

cupies. Approximately \$25,000 in cash and materials was added to the original appropriation by the members of this Association to enlarge, improve and equip the building. With the completion of the new building, the interest of the Association in the Department continues, and they are ever solicitous of its welfare and advancement.

The Annual or Winter meetings of the New Jersey Clay Workers' Association and Eastern Section of the AMERICAN CERAMIC SOCIETY are held at Rutgers College during the month of December. Owing to lack of accommodations, it has been the practice to hold these meetings in one of the other College buildings and it is a source of gratification to the Department that the Association can be fittingly entertained in its own quarters at future meetings.

The student organization, the Rutgers Ceramic Club, an offspring of the Ceramic Department at Rutgers College, holds monthly meetings during the College year. Lectures are given at each meeting covering some phase of the ceramic industry. An invitation to attend the meetings is extended to officers and employees of the ceramic plants in this district. The technical papers and ensuing discussions are proving very interesting to the students and a large attendance is always on hand.

The activities of the Ceramics Department have been considerably broadened by the act providing the appropriation for the new building. The Department has been officially designated as the "New Jersey Ceramic Research Station." Its functions are as follows:—

1. To provide a four-year curriculum in ceramic engineering.
2. To provide short courses in ceramics for practical clay workers.
3. To provide extension courses in ceramics in the ceramic centers of New Jersey.
4. To advise and assist the manufacturers of ceramic wares in the solution of technical problems arising in the industry.
5. To undertake researches for manufacturers under a system of contracts.
6. To conduct researches on problems of general interest to the ceramic industries and to publish the results of these investigations.

Located in the center of one of the greatest clay producing States in the Union and with the full coöperation and support of manufacturers of ceramic products in New Jersey, the Ceramics Department at Rutgers College has indeed an unusual opportunity for service in the advancement of the ceramic technology of her industries.

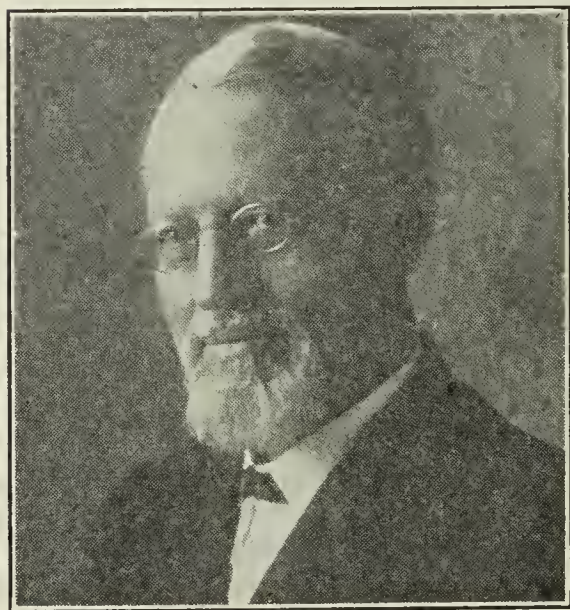
NEW BRUNSWICK, N. J.

HISTORY OF CERAMIC EDUCATION AT THE UNIVERSITY OF ILLINOIS

BY CULLEN W. PARMELEE

Ceramic education at the University of Illinois owes its origin to a plan originated and formulated in 1894 by Professor Chas. W. Rolfe who

was at that time Professor of Geology. He conceived the idea of the establishment of a "Laboratory of Economic Geology" at the University and prepared a little printed circular, a copy of which is before me, which discusses the necessity for state aid in the investigations of mineral resources of the state. In the "Bill for an Act to Establish a Laboratory of Economic Geology" which he prepared, it is specified that the director of the proposed laboratory shall collect samples of coal, clays, building stones, materials for the manufacture of glass, limes and cement, subject these samples to such analysis and *combinations as will demonstrate their valuable*



PROF. C. W. ROLFE

properties; publish bulletins and make a collection of raw materials and products. While the bill did not specifically mention instruction, yet it would have been an easy and logical procedure to use the staff and laboratories for the purpose. That, in fact, was the intention.

This bill had the cordial support of the Illinois Clay Manufacturers' Association and the coal miners. The president of the University approved the bill, but later the time seemed inopportune for this project.

Thereupon, Professor Rolfe was obliged to let the matter lie dormant until 1905

when he received the sanction of President James, who had recently been installed, to proceed with his plan. A vigorous campaign was undertaken to secure favorable action by the Legislature. Professor Rolfe had strong support from the Illinois Clay Manufacturers' Association and especially the active assistance of individual members who were untiring in their efforts. Special acknowledgment should be made for the assistance rendered by Mr. William Hammerschmidt, Mr. Frank W. Butterworth, Mr. John Stipes, Mr. W. D. Gates, and Mr. A. W. Gates, Dr. A. L. Converse, and Mr. D. V. Purington.

The Legislature responded favorably to the appeal by passing a bill in 1905 which provided for a State Geological Survey, and directed the University of Illinois to provide instruction in ceramic technology. The sum of five thousand dollars was appropriated for each of the first two years.

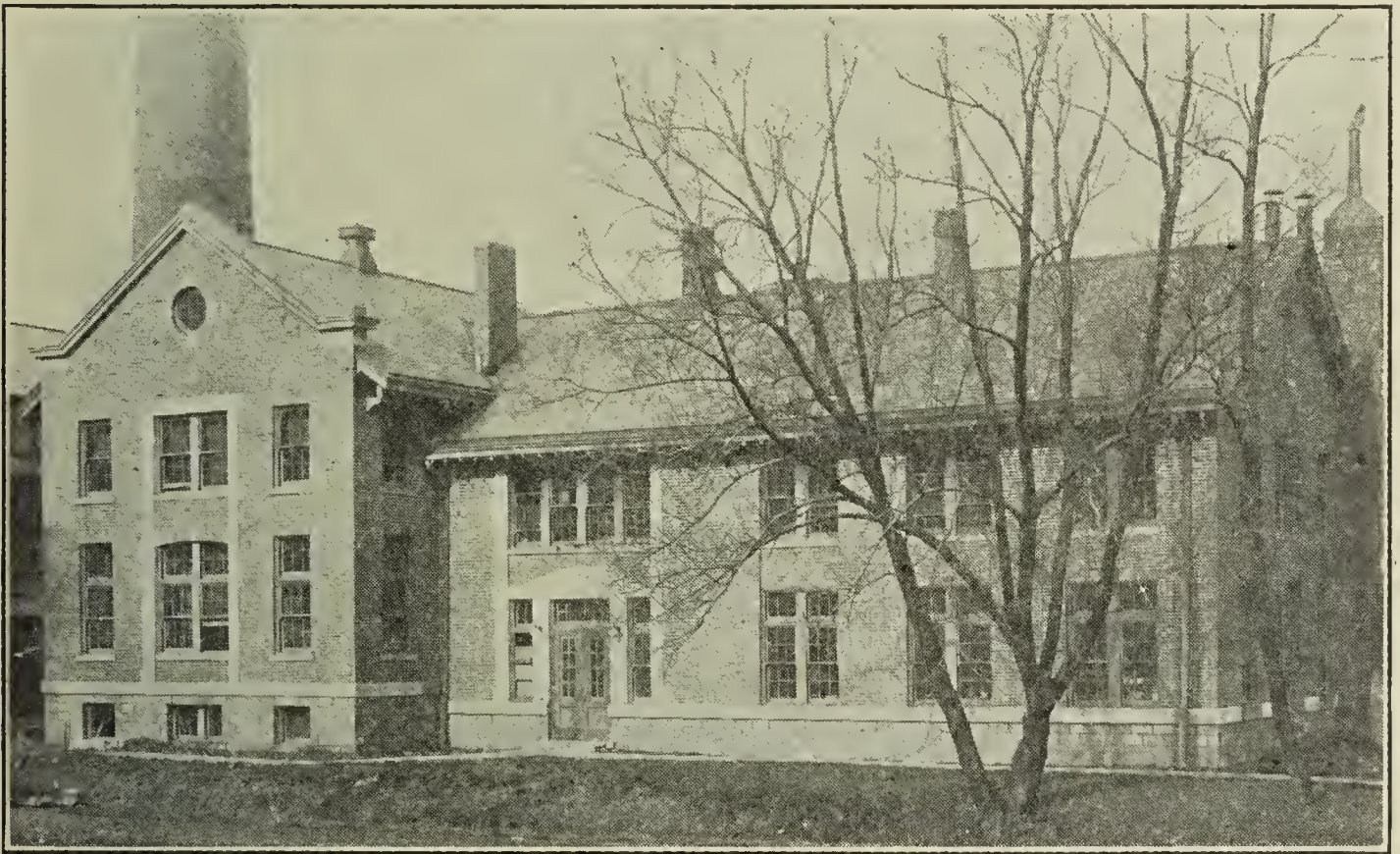
Professor Rolfe was appointed director and Mr. Ross C. Purdy was selected as the instructor.

The new department was housed in two rooms in the basement of the Natural History Building and a small kiln house was built at some distance from the laboratories. Two courses of study were instituted, one which contained a larger amount of cultural and pure science subjects, while the other had more engineering subjects.

Since that day of a modest beginning the department has steadily progressed. It early outgrew its small quarters and limited equipment. As more students enrolled the staff was increased and in rapid succession better facilities were acquired.

Owing to the limited space available for this history, it necessarily must be brief, therefore, only the most important developments can be summarized.

During the period between 1905 and 1910, Professor Rolfe was in charge, and the members of the staff were Mr. Purdy (1905-07); Mr. A. V. Bleininger (appointed assistant professor in 1907); Junius T. Krehbiel (1906-07); Ray T. Stull (appointed instructor in 1907); John McB. Knote (instructor 1908-11). The attendance increased from the initial five students to a



Ceramics Building (old).

maximum of twenty-one. An attempt was made to secure an appropriation from the Legislature for a suitable building. The first attempt failed, yet the annual appropriation for the department was increased to fifteen thousand dollars. In 1910 a two-story building was built, and the equipment was greatly improved.

In the period between 1910-1912, Albert V. Bleininger was Director and Professor of Ceramics, and Ralph K. Hursh was appointed instructor, 1911, and associate professor, 1921. The attendance reached a maximum of forty-five.

Mr. Bleininger left the department in 1912 to go to the newly created laboratory of Clay Products of the U. S. Geological Survey. Ray T.



Ceramics Building and kiln house (rear).

Stull succeeded him with the title of Acting Director of Courses in Ceramics (1912-15). During his administration the attendance reached a maximum of eighty-four undergraduate students; the industrial, that is, "Short Course," of two weeks' duration was instituted in 1913.¹ A kiln house was built and equipped with kilns, furnaces and machinery (1912) and the project of a new ceramics building was initiated which culminated in the appropriation by the Legislature of funds for the erection (1915-16) of the present three-story structure (see p. 100). New members added to the staff were Arthur E. Williams (1914-16); and Barney S. Radcliffe (1912-16). Other important changes were the transfer of the department from the College of Liberal Arts and Sciences to the Engineering College; the strengthening of the curriculum along engineering lines; and the dropping of the more general course in Ceramics.

For a few months after Mr. Stull left the department, Mr. A. V. Bleining was in charge, while on leave of absence from the U. S. Bureau of Standards. When he returned to the Bureau, Mr. R. K. Hursh assumed charge.

In September, 1916, Dr. Edward W. Washburn was appointed as Head of the Department and Professor of Ceramic Chemistry. Dr. Washburn had been connected with the Department of Chemistry for several years and during a part of that time had been head of the Department of Physical Chemistry. At the same time (1916) Cullen W. Parmelee came as Professor of Ceramic Engineering, and Howard C. Arnold (1916-17) as assistant. The department moved into its new building and additional equipment was procured. With the entry of the United States in the War, the attendance decreased to a small number (26) in 1917-18. After that it steadily grew until in 1921-22 there were seventy-two undergraduates. Additions to and changes in the personnel of the staff were as follows: Earl E. Libman, served as assistant and later as instructor (1917-22); Frank F. Footitt, research assistant (1917-18); Jos. E. Seabright, instructor (1918); Dr. Elmer N. Bunting, research associate (1920 to date); George R. Shelton, research graduate assistant and later Corning Glass Works Fellow (1921-22); J. Johnson (1917-19); Enoch G. Bourne (1919 to date), potter and laboratory demonstrator.

Aside from the improvements in the facilities for instruction, a significant development during the period was the character of the research. This was directed almost exclusively along the lines of the study by physical-chemical methods of fundamental problems in ceramics, such as the investigations of the viscosity of molten glass and methods for determining the porosity of burned clay wares.

The curriculum was broadened by the introduction of the "Ceramics"

¹This succeeded a briefer course which had been conducted by the Dept. under Prof. Rolfe.

Course. This resembles its predecessor of a similar name. It contains much more chemistry and less engineering than the course in Ceramic Engineering.

The school year of 1922-23 has begun with the department in charge of Cullen W. Parmelee¹ as Acting Head. Mr. Thomas N. McVay has been appointed to the staff as instructor. The attendance of undergraduates has increased to seventy-eight students.

Such having been the conditions under which the department has germinated and grown it is worth while considering the results.

During all these years, those in charge recognized the obligations of the department to the state and to the industry. If any motto should be chosen to describe the aspirations of its leaders it would be the word "service." Many are the requests which have come for information and advice, and many have profited by such assistance. The organization of the Industrial or Short Course in 1913 was inspired by the desire to serve the interests of the clay workers of the State who had enthusiastically and persistently urged the needs of the department. The success of these short courses may be judged from the numbers attending which reached seventy in 1922, and also by the wide diversity of interests and the many states represented—twenty at the latest session.

It is quite impossible to discuss in detail all of the contributions of investigation and research made by members of the staff during the department's history. We can indicate only a few of the more conspicuous achievements; for example, the important papers by Purdy and co-workers on fritted glazes, crystalline glazes and pyrochemical behavior of clays; Bleininger's study of the heat distribution in industrial kilns and the pre-heating of highly colloidal clays as a method for rendering them available for use; Stull's studies of porcelain glazes and slips for enamel brick; Hursh's investigations of the heat balance of ceramic kilns; Washburn's and co-workers' contributions on gases dissolved in glass, methods for determining porosities and the measurement of the viscosity of glass. Purdy, Bleininger, Stull, Hursh, Williams and Parmelee have prepared or assisted in the preparation of reports on the clay resources of this and other states.

With regard to the graduates of the school, it is well to note that the department has always insisted upon the completion of four years of undergraduate work as the minimum training for a young man preparing for effective service in the ceramic industry. A total of eighty-one men have completed such training and have received the traditional "sheepskins." They are distributed as follows:

Heavy clay products.....	16
Misc. whiteware.....	11
Refractories and abrasives.....	12

¹ In 1918-19, while Dr. Washburn was absent on leave, Prof. Parmelee was in charge.

Glass.....	6
Enameled metals.....	3
Terra cotta	4
Ceramic instruction.....	2
Misc. or not known.....	23
Dead.....	4

Seven men have received the Masters Degree in Ceramic Engineering, and two have majored in Ceramic Engineering for the doctorate.

This history will be incomplete without a brief statement regarding the courses of instruction, building and equipment. As already indicated, there are two four-year courses, Ceramics and Ceramic Engineering. In both courses the studies are prescribed, although a limited amount of freedom in the choice of non-technical and technical electives is permitted. The plan of instruction in both courses naturally provides for the necessary preliminary training in the fundamentals, *i. e.*, rhetoric, chemistry, physics, and mathematics. The general principles of ceramic technology are reviewed and an opportunity is afforded advanced students to choose electives dealing with highly specialized branches of the industry, such as cement, glass, enamels, etc.

When the department was inaugurated it was provided with two rooms in the basement of the Natural History Building. Special provision had to be made for the kilns so a small brick building, about twenty feet square was built. This also housed the dry pan. This building was informally known as Purdy Hall.

In 1909 the Illinois Clay Manufacturers' Association issued a circular which states that the department is obliged to use "a room or two in the basements of each of three buildings scattered over a distance equivalent to three city blocks." This condition was relieved by the erection of a two-story brick building with basement having a total floor space of 6036 sq. feet. This building was situated about one hundred feet from the old kiln house, Purdy Hall, which was an improved but not an ideal condition.

In 1912 a one-story brick building was built one block distant as the first unit of a new ceramics plant. This building has a total floor area of 11,200 square feet and is used in part by the mining department. It contained a kiln room of 4300 square feet and also offices and classrooms for the department.

In 1915-16 the present ceramics building was constructed. This adjoins the kiln house, just described. The building is a three-story edifice covering a ground area of 67 x 189 feet. The ceramic engineering department uses one-half of the basement for storage and plaster shop, one-half of the first floor for offices, storeroom, laboratories and clay shop; the second floor is used entirely by the department for research laboratories, offices, museum, recitation room, lecture rooms, and reading room.

The equipment of the department includes very complete installations for the manufacture of brick of various kinds, drain tile and hollow ware, pottery and floor tile, saggers, and special refractories, enamels, glass and cements.

The furnace equipment includes a Morgan gas producer, three laboratory coal burning and two oil burning kilns of considerable size, a decorating kiln, an enameling furnace, a small furnace with preheated air and gas supply, a battery of five frit furnaces with preheated air and gas supply, and miscellaneous small furnaces for fusion tests, etc.

The student organizations which have been identified with the department began with the Ceramics Club which dates back to 1907. This was succeeded in 1916 by the University of Illinois Student Section of the AMERICAN CERAMIC SOCIETY. In 1915, Keramos, a fraternity was organized by a small group of students who have conducted its affairs according to the usual practise for secret societies.

Research has been fostered by the relation of the department to the Engineering Experiment Station. A Research Associate in Ceramic Engineering is a member of the Department staff and several Research Graduate Assistants have been appointed to the station staff to conduct their investigations under the direction of members of this department.

URBANA, ILLINOIS

DEPARTMENT OF CERAMIC ENGINEERING OF IOWA STATE COLLEGE

BY PAUL E. COX

The first mention made of instruction in ceramic engineering at Iowa State is found in the catalog of 1899-1900, under Samuel Walker Beyer, Professor I. A. Williams instructor. No students enrolled for the course, which was a two-year course only. The work was to be taught without very much in the way of equipment, and it is interesting to note that ceramic engineering was tied to mining engineering, which was in turn a part of the geology department.

There were no changes until 1906-1907 at which time a course in Ceramic Engineering was authorized by the legislature and this new department together with the Department of Mining Engineering moved from Morrill Hall into the new Engineering Hall. Two courses in Ceramics were offered, the one being the two-year course and a four-year course, which really was a five-year course because it called for a year in residence of what is termed an "Academic Year." This Academic Year was nothing more nor less than a year to make up entrance requirements.

The Department of Ceramics, or rather Course in Ceramics, was established by a mandatory act of the state Legislature in obedience to resolu-

tions passed by the several ceramic goods manufacturers' associations of the State. These actions began in 1899 in the shape of a resolution toward this end by the Iowa Brick and Tile Association, renewed each year until action was taken by the legislature. In 1906 the Iowa Cement Users' Association joined with the preceding organization in a resolution favoring the establishment of a School of Ceramics, and finally a bill was prepared, presented to the legislature and enacted into a law providing for the work in ceramics at Iowa State College and, in two sections, states what is to be done in the department of ceramics. In brief the Department was expected to furnish instruction in the various branches of ceramic practice and to carry on work in the Engineering Experiment Station in research work of value to the industries listed as ceramic industries.

Anson Marston was Dean of the Division of Engineering, Winifred F. Coover, now head of the Department of Chemistry of the entire college, was Assistant Professor of Chemistry, Professor Beyer and I. A. Williams had in immediate charge the ceramic courses.

The course of study was similar to that laid down by Professor Orton. No students appeared.

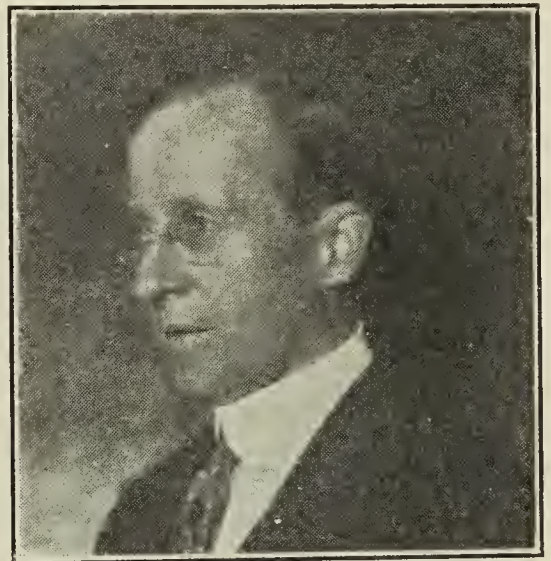
It should be understood that the research work of the faculty had been going on for some years however, and on the one hand Professor Beyer and his staff of geologists had been getting into the matter of sources of raw materials, and Dean Marston had been working on crushing tests, on common brick and other burned clay products.

In the catalog for 1907-1908 appears the name of a student who apparently did not know of ceramics for he was not enrolled in the course though his name appears. This student was Milton F. Beecher who ultimately became the first graduate of the Department of Ceramics.

In 1910-1911 the ceramics building was built as a part of the building known as the Engineering Annex. This is the building now occupied in part by the Department. A part of this building is used by the Engineering Experiment Station in its ceramic work.

In 1912-1913 Milton F. Beecher's name appears as instructor in the department.

In 1914-1915 Iowa State College undertook to offer five-year courses and in the catalog of that year the ceramics students are urged to take a four-year course in mechanical engineering and to follow it with a fifth



PAUL E. COX

year of special work in ceramics. The name of Amos. P. Potts appears as Associate Professor, and Sidney L. Galpin's name appears as Assistant Professor in geology. Potts was fresh from Ohio State University and Galpin from Cornell and the hands of Dr. Ries.

The catalog of 1915-1916 shows the course in ceramics to be headed by Professor Beyer, with Homer F. Staley as Associate Professor and S. L. Galpin as Assistant Professor. There were four students enrolled. The next year there were nine students.

In 1917-1918 Dr. Galpin left and Professor Beyer and Professor Staley handled the work alone, there being seven students enrolled. In 1918-1919 Professor Staley left for work in the Bureau of Standards, and was replaced by Dr. Galpin. During the War Dr. Galpin was in charge, with O. J. Whittemore as Assistant Professor in ceramics. Remembering the fact that the World War had shattered the organization it is not surprising to find but three students enrolled for work in ceramics. Professor Beyer had become Dean of the new division of Industrial Science and in general a new organization had to be effected, with Dr. Galpin the only mature person in charge of the work, and with an overload of teaching in both mining and ceramics.

Professor Whittemore resigned in the fall of 1921 and Paul E. Cox came into the faculty. Dr. Galpin was in charge during the year of 1921-1922 and was then relieved from direct work in the Department of Ceramics and was so enabled to give full time to his work as Associate Professor of Geology. In the fall of 1922, Prof. Cox was placed in charge of the work of the department and D. A. Moulton was added with the rank of Assistant Professor. It has always been customary to have at least one man on the staff to give half time to the work of the Experiment Station and Prof. Moulton was appointed for that work.

Since 1915 work has been given to students of the Division of Home Economics and others in modeled pottery. Miss Ethel J. Bouffleur from the University of Washington was selected to conduct these courses.

There have been from 10 to 14 students entered for the four-year course the past three years, and there have been as many as 60 students per quarter from other departments for work in modeled pottery. There has never been fewer than 20 enrolled for this popular course.

Since Iowa is state endowed with materials suitable mainly for brick and similar products the stress in the engineering work is placed on the heavy products. The course of study is about the same as that of other schools.

Since half of the work of the department is the Engineering Experiment Station work it should be pointed out that the pioneers did fine things in the Bulletins they prepared. Beecher's work on the fire clays of Iowa was negative but conclusive. Staley put out several bulletins, timely and

useful. Whittemore with Whitford, a graduate student, produced a Bulletin on glazes possible for pottery work on Iowa clays, and this Bulletin has been a popular one.

A fine new kiln has been built, with capacity for 800 pavers or the equivalent. A high temperature furnace of the sort described by Prof. Moulton at the St. Louis meeting is being constructed. A heavier motor has been added, and many pieces of machinery placed that had been bought and never used.

IOWA STATE COLLEGE
AMES, IOWA

CANADA'S FIRST CERAMIC SCHOOL: UNIVERSITY OF SASKATCHEWAN

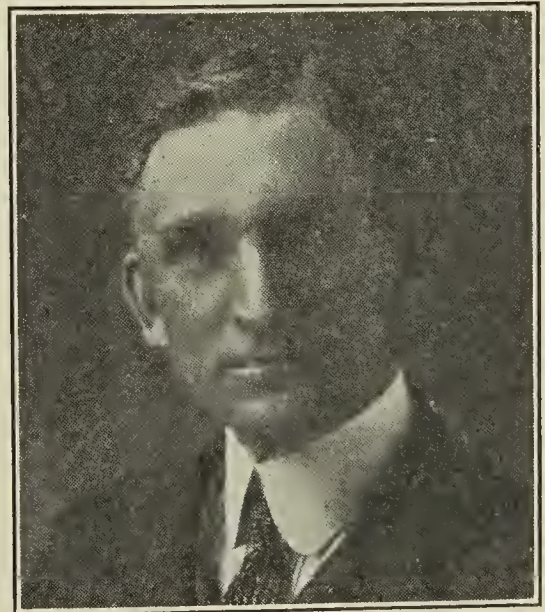
BY W. G. WORCESTER

That a new country may grow it must have people. To first attract and later to hold and support a population there must be a development of the natural resources of that country. The development may be along agricultural lines or those dealing with the basic materials of a metallic or non-metallic nature, though better still through a simultaneous exploitation of both.

Had the western provinces of Canada taken cognizance of the above fundamental principle from the start their census figures might not have shown the remarkable per cent gains as were recorded, but a far more substantial foundation of proper balance would have been formed.

That the country could not exist indefinitely on the sub-dividing of perfectly good ranch lands into town lots was forcibly and undeniably impressed upon the builders of western Canada by the War, as early as 1914. During the years of that great struggle all of Canada responded, literally speaking, to the last man. The lull, however, thus created in the daily life of the Dominion gave time for the thinking minds to survey the work of the past, and, in light of the mistakes that had been made to plan for the morrow along lines of sane stability.

It was apparent that the foundation for this stability must be built upon the country's natural resources, investigations and surveys were started with that object in view; notably was the important work by Ries and Keele on the Clays and Shales of Western Canada followed by a valuable



W. G. WORCESTER

investigation by Mr. N. B. Davis, M.A., B.Sc., on the Clays of Southern Saskatchewan¹ for the Department of Mines, Ottawa.

The work of Davis proved the existence of large deposits of valuable clays in Saskatchewan; these clays were shown to be suitable for many lines, particularly structural wares, sewer pipe, refractories and pottery of several grades.

The Provincial Government of Saskatchewan with true western spirit was awake to the great possibilities and value of the latent clay resources, to their province, championed largely by the Hon. Chas. A. Dunning,² provincial treasurer and minister in charge of the Bureau of Labour and Industries. Much thought and consideration was given to the question as to the best methods of assisting in the building up of a permanent ceramic industry in Saskatchewan.

That much remained to be done from a technical point of view was obvious; over the province were numerous clay plants in various stages of development, successes and failures, largely the latter. Why was this the case? Interests were asking as to the possibilities of locating in the province and as to the nature and qualities of the clays; all of these with other problems naturally led to the question of a technical ceramic man, and in the advent of the development of the ceramic resources, where could the trained minds to carry on the work be found?

The discussions led to a consultation early in January, 1921, with Dr. Thor. Thorvaldson, Ph.D., head of the department of Chemistry, University of Saskatchewan. Dr. Thorvaldson proposed that the University establish a department of Ceramic Engineering, the head of the new department to work jointly between the University and the Saskatchewan Government in the development of a course in ceramic engineering, and, to act in a consulting way to the industry of the Province as a whole.

The President and Board of Governors of the University concurred in this arrangement with the provincial government, thus making it possible for the establishment of the first ceramic school in Canada.

The task of finding a suitable man for the position was assigned to Dr. Thorvaldson, realizing that the duties of the new instructor would not only involve technical but a practical knowledge as well, and, furthermore, a knowledge of Western Canada clays, combined with that of general business methods and conditions in a new country, were essential though not entirely necessary. Thus the field of suitable or available men was somewhat narrowed.

Among the list of names suggested was that of W. G. Worcester, a product of the early ceramic days at Ohio State University. Upon leaving the University in 1899, Mr. Worcester was engaged in the constructing

¹ Published in 1918.

² At present, Premier of Saskatchewan.

and operating of clay plants until his return in 1908 to act as assistant to Prof. Orton and later with Prof. Purdy. In 1912 he moved to Calgary, Alberta, Canada, and has spent the past 9 years in developing and studying the clays of Western Canada. In view of the qualifications of Mr. Worcester he was tendered the position as director of the new ceramic department; the offer was accepted and the new duties were undertaken in May, 1921.

During the past two years, in addition to the field work of collecting samples, visiting and assisting each of the clay products' plants, the work of building up the department of ceramics has been under way. Equipment, for the most part, had to be imported, shipments and delivery were slow, in fact the problem was quite different from what it would have been in a well developed country.

The course selected is one of four years, following somewhat the lines of the four-year ceramic course in the Universities of Ohio and Illinois, the aim being to give the student a general training in sciences, chemistry, physics, German or French, geology and the general principles of clay working, rather than to specialize on certain ceramic lines.

The matter of a short course has been left open but will not likely be included. In view of the ultimate need of trained or skilled workmen, it is felt that a trade school more on the lines of the English or German schools would prove more helpful in the building up of the industry than would that of a short course.

The department of ceramics is housed in the engineering building where power, air and other similar facilities are available. Up to the present a single room has been used but the volume of work has so increased that plans are now under way to increase the space by the addition of two additional rooms. The original room will then be used for kilns, clay grinding and preparation, as well as plaster work.

The second room will be equipped with a full line of pottery machinery, supplies for body and glaze making, their preparation and general student work.

The third room is to act as a classroom and economic material museum with samples or specimens of ceramic products, largely of Canadian production.

The equipment consists of an oil fired muffle kiln, pot and Deville furnace and frit kiln, jaw crusher, a special built three roll crusher, screens, ball mills, potters wheel with pull down, small auger machine with cutter, repress and dry press, in fact a general line of ceramic machinery that is being added to as rapidly as space will permit.

A new kiln is now being designed in which to test the application of Saskatchewan lignite coals to ceramic work; the kiln is to be so constructed that ordinary grates with natural draft may later be altered to forced

draft, powdered fuel, and finally to the use of producer gas. A small producer is to be built for this purpose.

The list of students, in the nature of the case, is somewhat limited. At present there are two third-year men. As to the number of students in their first and second year that may later take ceramics there is no means of knowing. All engineering students, including chemical, take work that is more or less in common during their first two years, but from present indications and interest shown there will be a fairly large number elect ceramics as their subject among the engineering courses.

As an assistant in the laboratory the duties are very efficiently carried out by Mr. W. H. Phipps, a man of broad experience in the working of clays in many lines. The early training of Mr. Phipps was in Great Britain with the Leeds Fire Clay Company, and later with the Williscroft Potteries at Hanley. He came to Canada in 1912 and has been continuously connected with western ceramic work since that date. Thus his services to the department from a practical point of view, combined with his knowledge of Western Canadian clays and conditions, are exceedingly valuable.

DEPARTMENT OF CERAMIC ENGINEERING
SASKATOON, SASKATCHEWAN

CERAMIC WORK AT THE UNIVERSITY OF NORTH DAKOTA¹

The ceramic work at the University of North Dakota had its conception in the research work of the School of Mines on the high grade clays of the state. The courses of instruction are constantly being extended and other courses added. Ceramic electives are given to students in mining and industrial engineering. The classes in pottery are successful especially in the production of high grade stoneware and earthenware. There is also considerable interest in art pottery. In addition to the instructional work a large amount of technical and practical data on undeveloped clays of North Dakota is being accumulated.

THE CERAMIC ENGINEERING DEPARTMENT OF THE UNIVERSITY OF WASHINGTON, SEATTLE

BY HEWITT WILSON

Ceramic engineering was established at the University of Washington in 1918, as a department in the College of Mines. At the same time investigations in ceramics were begun as part of the program under the co-operative agreement existing between the University of Washington and the United States Bureau of Mines, which maintains its Northwest Ex-

¹ For full description and pictures see *Jour. Amer. Ceram. Soc.*, 5, 140-45 (1922).

periment Station on the University campus. The department shares with the coal mining, metallurgy and electrometallurgy departments of the Bureau in an annual appropriation of ten thousand dollars from the State of Washington, besides the usual maintenance provided for the College of Mines.

The director of the ceramic work holds an assistant professorship in ceramic engineering with the University of Washington and acts as consulting ceramist for the Northwest Experiment Station. A technical assistant for laboratory work is employed by the University, and an annual ceramic fellowship of \$780 for graduate students is provided from the State coöperative fund. Ira A. Williams was in charge for the first year and Hewitt Wilson has directed the work since the fall of 1919.

Purposes

Coöperation with the Industries of the Pacific Northwest.—A ceramic laboratory occupying 7,350 sq. ft. total floor space has been built and equipped with the best types of ceramic machinery.

The building itself is a fine example of construction with ceramic products. It is the only public ceramic laboratory on the Pacific Coast and compares very favorably with the best in the eastern parts of the United States. The neighboring industries are encouraged in the use of the laboratory and the departmental library for their experimental and testing work, or they may employ members of the staff during extra hours for special problems. A large part of the general research work of the department primarily



PROF. HEWITT WILSON, University of Washington, U. S. Bureau of Mines.

consists of coöperation with the industries of the Pacific Northwest. The structural wares, Portland cement, lime, plaster, stoneware pottery, and clay refractory industries are well established. The market is ready for local whiteware, ornamental tile and glass products. A future market for magnesia and silica brick, special refractories, diatomaceous earth insulating brick, and enameled metals is developing. It is the work of the ceramic department to locate, classify, and test the raw materials for these new industries.

Research Work, Testing the Clays of Washington.—In the years 1919 to 1922 coöperation was arranged with the Washington State Geological Survey and the U. S. Bureau of Mines to cover the examination of properties and the collecting and testing of clay samples from all parts of

the State of Washington. A report of this work has been written and is in the hands of the publishers. It shows that the State has within its boundaries almost every variety of clay. Prominent among the State products are the following: Residual kaolins from the "Inland Empire" of Eastern Washington; buff-burning, plastic, lacustrine clays from the same region; Eocene shales from western Washington; Pleistocene red-burning clays from southwestern Washington; glacial clays from the Puget Sound area; basaltic clays from southwestern and eastern Washington; refractory clays from the Sumas, Green River, Napavine and Spokane districts; terra cotta, stoneware and buff-burning pottery clays from the Green River and Spokane districts. All varieties of red-burning structural wares can be made from the shales and the glacial, Pleistocene, and basaltic clays. And if the kaolins from eastern Washington and Idaho are used in conjunction with the feldspar deposits of Avon (Idaho), Ruby (Washington), or those of British Columbia, it may be possible to produce a high-grade whiteware body from all Pacific Northwest materials.

The Pacific Northwest can become nearly independent as to ceramic materials, because, besides the above clay materials the following are found: Diatomaceous earth in Kittitas and Grant Counties of Washington, and Crook County, Oregon; magnesite deposits in Stevens County, Washington; numerous quartzite deposits in Pierce and Stevens Counties, Washington; vein quartz in Spokane and Chelan Counties, Washington, and chromite in Oregon. In addition, Alaskan gypsum is being burned for calcined gypsum at Tacoma, and three large Portland cement plants in Washington are supplying the Portland cement for the Pacific Northwest.

While the structural ware plants are already well established, the three terra cotta companies are looking for new buff-burning clays to improve their bodies and reduce the cost of hauling.

Citizens in the southwest district, particularly around Gray's Harbor and South Bend, have been asking for local materials suitable for the common structural wares. At the present time no company is operating in that district. The clays found there have been studied and quite a number were found suitable for this work.

The clay refractory industry, which was given a start in the Pacific Northwest during the War, has been aided by the testing and sorting of all the available fire clays.

The knowledge of the location of the kaolins of eastern Washington and northern Idaho, as determined by the survey made, will be of value to the whiteware manufacturers of the East.

This is one of the first State surveys of clays made in which the newly adopted standard methods of testing of the AMERICAN CERAMIC SOCIETY have been tried out. Since the survey covers a wide variety of clays,

the general conclusions drawn will be of value in other ceramic centers.

Testing the Clays of Idaho.—Coöperation was arranged with the Idaho Bureau of Mines and Geology for the testing of clay samples and the writing of a report, entitled "A Preliminary Report on the Clays of Idaho," by Frank H. Skeels and Hewitt Wilson, published as Bulletin No. 2, 1920, by the Bureau of Mines and Geology, at Moscow, Idaho. Large quantities of kaolin and buff-burning clays are found in the Inland Empire region of western Idaho.

In connection with the testing of this large number of clays, two laboratory instruments were devised. A new mercury volumeter¹ was constructed by Ernest F. Goodner, and an oxygen-acetylene fusion furnace² was devised by Hewitt Wilson.

The preliminary survey of the ceramic materials will be followed by separate studies of the different classes of materials. After testing a number of whiteware mixtures, using the eastern Washington and Idaho kaolins and feldspars, a report was prepared which has been sent to the AMERICAN CERAMIC SOCIETY for publication. A thesis report was prepared by Ernest F. Goodner on four of the typical fire clays of the State, including a flint fire clay, a shale-like fire clay, a residual kaolin and a soft, fine-grained and plastic bond clay.

Laboratory tests will be made on the other valuable ceramic raw materials of the State, such as the quartzites, quartz for glass sand, Tertiary shales, glacial clays, etc., and reports made from time to time.

Super-refractory Studies.—In coöperation with the electrometallurgical department of the Northwest Experiment Station, considerable research work has been done with clay and sillimanite mixtures which have been fused in the electric arc furnace by the electrometallurgists and tested by the ceramists. It has been fortunate to have at hand electric furnace equipment such as is possessed by very few ceramic laboratories, operated by skilled electrometallurgists. Melts of 200-pound lots can be made. This study will be continued with work on melted magnesia, spinels and chromite, under the general heading of "Super-refractories."

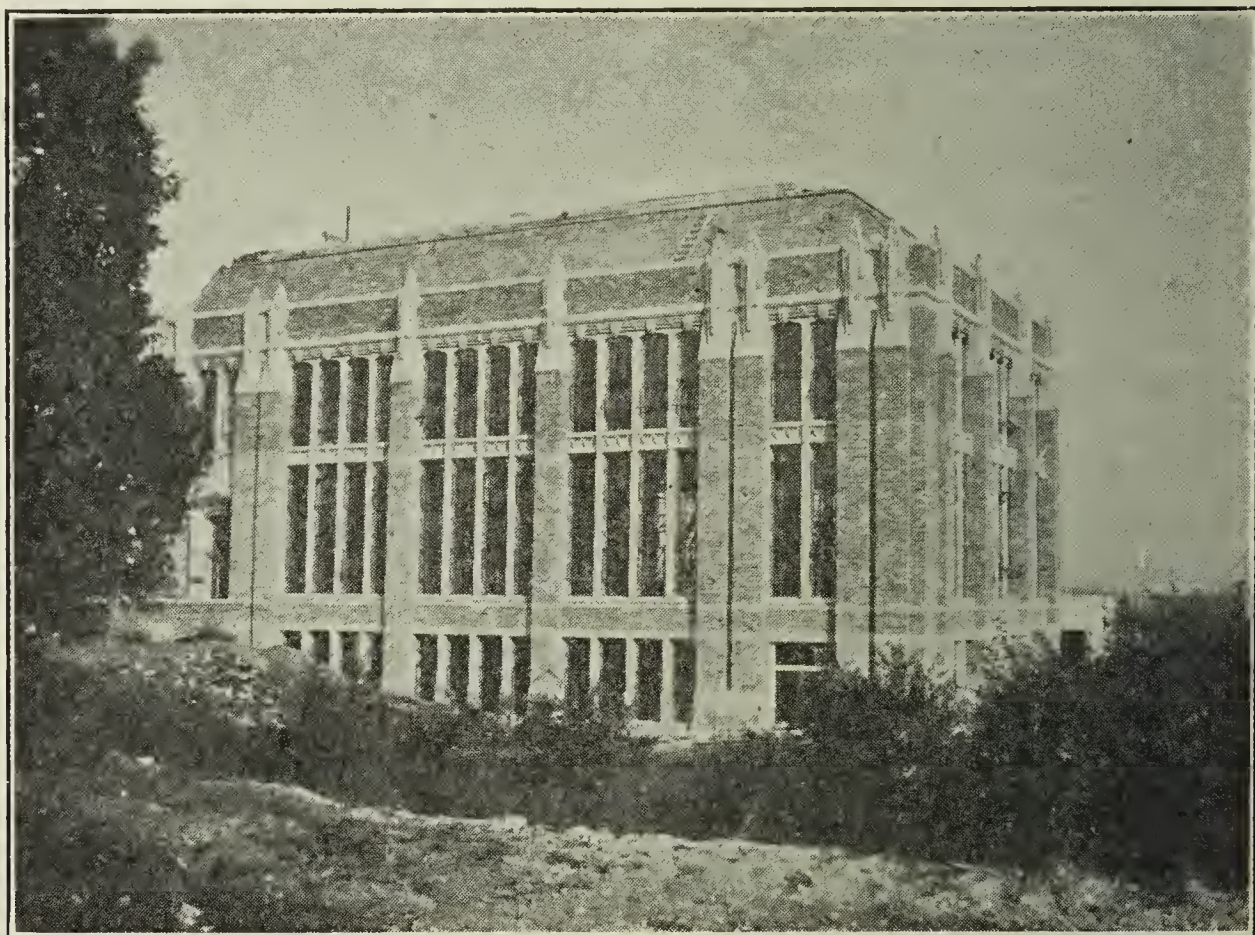
Clay Testing.—Several hundred samples of clays and other non-metallic materials have been sent in for testing from Alaska, British Columbia, Alberta, Washington, Oregon, California, Idaho, Montana, Utah, Colorado, and Central America. A preliminary firing treatment to determine the type of the clay or a microscopic examination to determine the nature of the mineral is made without charge.

¹ E. F. Goodner, "A Mercury Volumeter," *Jour. Amer. Ceram. Soc.*, **4**, 288 (1921).

² Hewitt Wilson, "An Oxygen-acetylene High-temperature Furnace," *ibid.*, **4**, 835 (1921).

Educational

A 4-year curriculum in ceramic engineering has been developed and tried out. It is based on the ceramic instruction given at the Ohio State University and the University of Illinois. During the development period of this complete program elective courses in cements, limes and plasters, refractories and general ceramics have proven popular with the civil, metallurgical, and chemical engineering students.



Ceramics Building, University of Washington.

Two degrees of Master of Science in Ceramic Engineering and one Bachelor of Science degree have been granted to date. These graduates are now doing creditable ceramic work with clay companies in the State of Washington. At the present time, the ceramic student body consists of one fellowship and four undergraduate students. Students in the College of Fine Arts, especially in architecture and design, make use of the ceramic equipment and laboratory space. Mrs. Eugenia Worman is in charge of the class in pottery design. The ceramic department is rapidly becoming known as the educational, technical and research center for ceramics in the Pacific Northwest.

CERAMIC ENGINEERING DEPARTMENT
UNIVERSITY OF WASHINGTON

SCHOOL OF INDUSTRIAL ART, CITY OF TRENTON

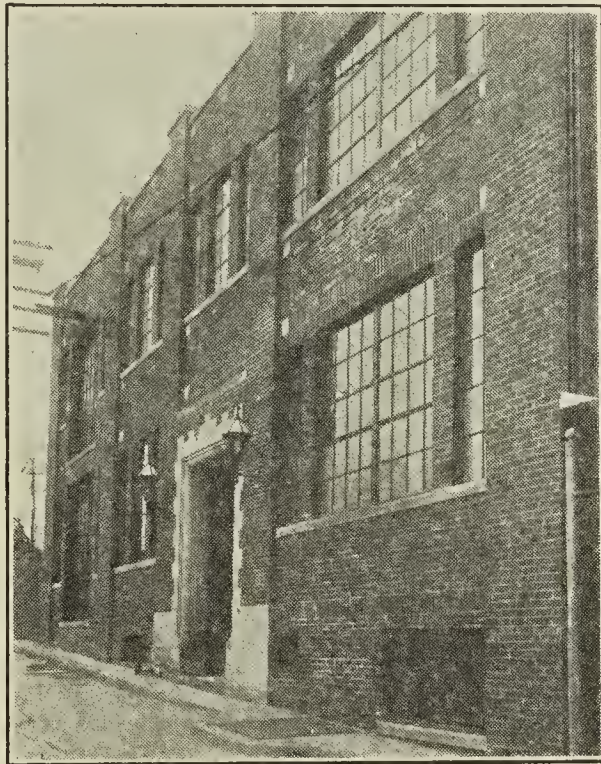
BY F. F. FREDERICK

The work of the Department of Ceramics of the School of Industrial Art of the City of Trenton is carried on in evening classes only, as all of the men enrolled are employed in the potteries of the city and vicinity.

The course covers four years, two and three evenings per week. The first year is devoted to general chemistry, the second to qualitative analysis, the third to quantitative analysis, and the fourth to applied ceramics and ceramic engineering.

To secure the diploma men must produce a "masterpiece" in which either artistic quality or technical workmanship, or both, is shown; or to the development of an invention or a device that will improve some process of clay manufacture, in which the originality of the idea (not necessarily patentable) and the technical workmanship are given equal weight.

The work of the class in applied ceramics is devoted to the construction of pottery. Each man weighs his own mix, goes through the regular routine of the slip-house, casts, throws or presses a piece of pottery, and prepares it for the kiln. After the burn he prepares and



Shop Building, The School of Industrial Arts of the City of Trenton. Half of this building is devoted to clayworking. The equipment was contributed to the school by the manufacturers of Trenton and vicinity.



FIG. 1.



FIG. 2.



FIG. 3.

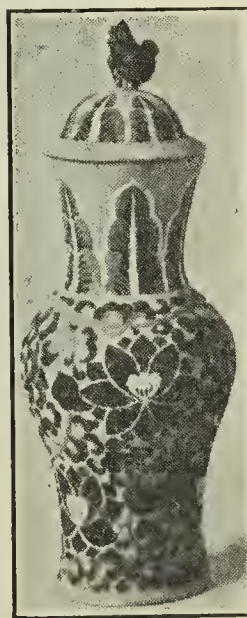


FIG. 4.

applies a glaze and completes his product. In special cases men with little or no knowledge of chemistry are admitted to this class.

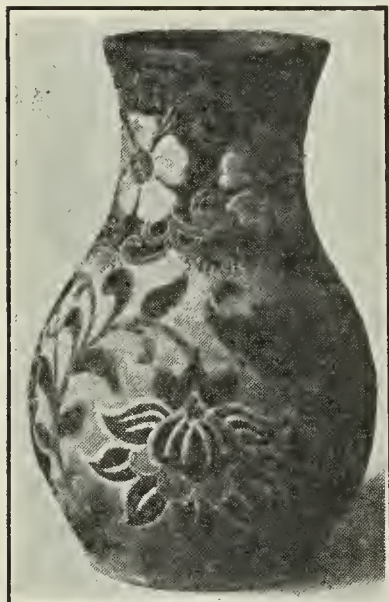
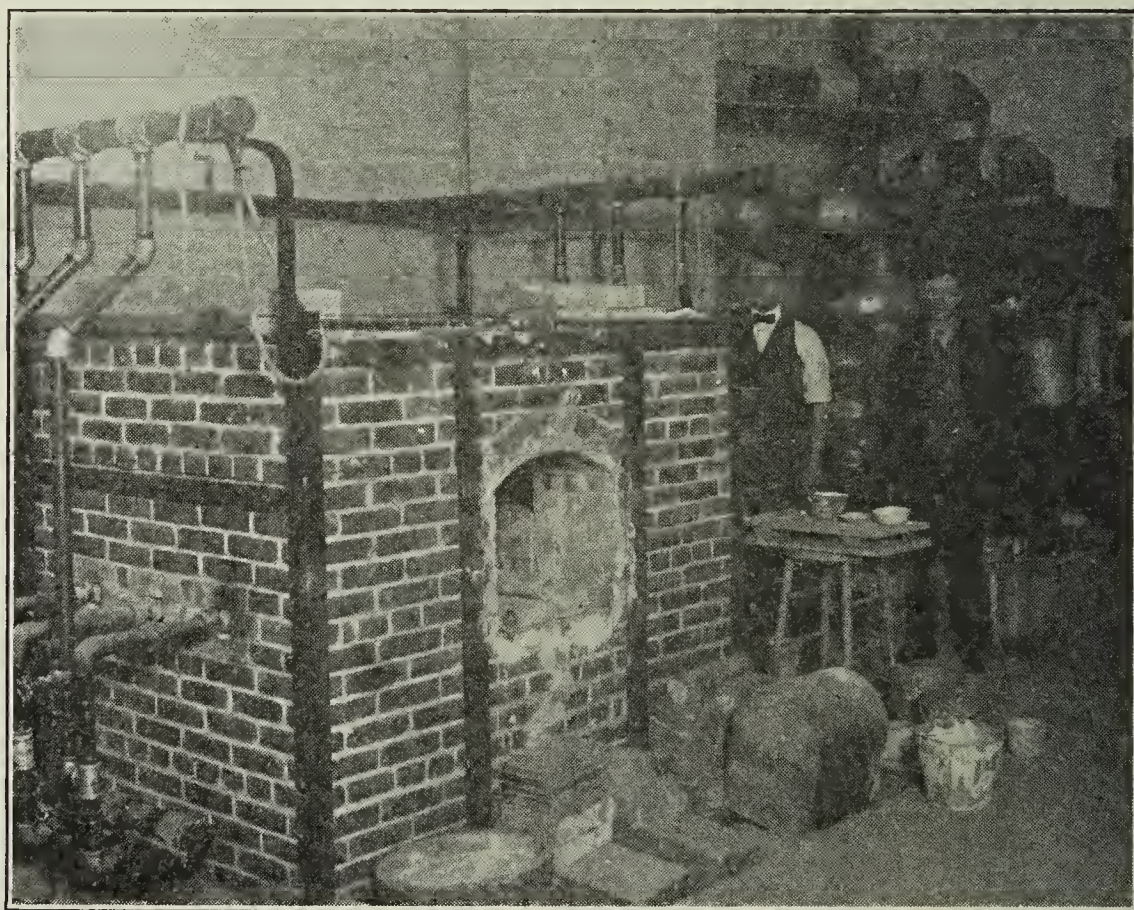


FIG. 5.

In the class in ceramic engineering (two years of work in the Department of Chemistry required for admittance) the application of chemistry to ceramics is made, and, by means of lectures and discussions, the subject in its relation to the every-day problems of each man is considered. Twenty-five men are enrolled in these two classes.

For men interested in the art side of pottery a course in modeling is offered.

The Ceramic Department is in charge of Mr. Joseph Johnson, Ceramic Engineer with the Trenton Potteries Co., assisted by Mr. Alfred C. Grainger. The modeling is in charge of Mr. Harry Rosin. Mr. Frank F. Frederick is the Director of this School in which over thirteen hundred students are enrolled in all departments.



A corner of the kiln room, Department of Ceramics, The School of Industrial Arts of the City of Trenton.

CERAMICS AT NEWCOMB COLLEGE

The School of Art, Newcomb College, New Orleans, Louisiana, includes classes in Pottery Decoration, Pottery Making, Ceramic Chemistry, Overglaze Decoration.

The classes in Pottery were started in 1896 with a group of students from the art school already prepared from the standpoint of design and drawing. Experiments were made with native clays; flowers, fruits, trees which were in profusion both winter and summer were used in decoration with a combination of blues, greens and yellows, all forming a certain character and individuality by which the standard Newcomb pottery is known.

The pottery won its first public recognition at the Paris Centennial in 1900 where it won a medal. Many other honors have been awarded it since.

The Newcomb Hand Built Pottery affords a very personal product as the pieces are built, glazed and fired by the one person. On these pieces there is little or no decoration, the appeal coming only from the form, color and texture of glaze.

OUR CERAMIC JOURNALS

The "power of the press," exemplified by the ceramic journals, has at all times been potent in its support of scientific and technical research and of plant control. They are effective media for exchange of information between the scientists, artists, engineers, equipment builders, and the manufacturers of ceramic products. They have rendered the ceramic crafts a much more valuable service as purveyors of scientific and engineering information than of current trade news items. They have at all times advocated organized coördination and coöperation in research.

The AMERICAN CERAMIC SOCIETY recognizes them as contemporaneous agencies responsible jointly with the SOCIETY for the advances which have been made during the past twenty-five years.

THE CERAMIC TRADE AND ITS OLDEST PAPER

BY STILLMAN TAYLOR

This is a brief story of forty-eight years of progress. There are few departments of industrial art which have advanced more rapidly during the past half century than has ceramic manufacture, and the history of *The Crockery and Glass Journal* parallels closely the expansion of the pottery and glass manufacturing industries in this country. As a trade journal dedicated to the trades service, "The Old and Reliable," as a good many subscribers refer to us, has from its initial number hewed close to the line and that line has been to publish the most accurate and the most useful trade paper in the field. It is chiefly due to this faithful endeavor to print all the important news which is of interest and value to the distributor of ceramic wares and to print nothing else, that *The Crockery and Glass Journal* has achieved the reputation of being the oldest and the most representative publication in its own sphere of trade.

Under the name of *The Crockery Journal* the first issue appeared Nov. 28, 1874, bearing the publishing imprint of Geo. Whittemore & Co., 103 Fulton Street, New York. This issue consisted of eight pages and the salutatory on the editorial page said, "We start without a competitor and hope to earn the approbation and hearty support of the trade by publishing a high class semi-monthly journal, treating of crockery, china, earthenware, glassware, porcelain, bronzes, decorations, etc." *The Crockery Journal* was launched in the year when oil lamps with pendant and lowering and raising fixtures were the big feature in novelties, in the period when the self-lighting gas burner was introduced and when Trenton was first referred to as the Staffordshire of America.

When the first issue of the *Journal* appeared the tariff was a topic of much controversy and singularly enough, there was also a disagreement among pottery manufacturers and workers then as now. In the January

number of the *Journal* a news article says that, "In December, 1874, the wage difficulties between manufacturers and workers at Trenton, N. J., was settled by the former declaring that no further reduction in wages would be made. The workers formed a union and among the resolutions was the following, 'That we use our moral force with the manufacturers in maintaining the present tariff unchanged, being convinced that it is to our mutual interests to do so.' About one thousand pottery workers were interested in this movement and an able man averaged \$18 a week when on full time."

In comparing the present with the past, and 1922 with the year 1874, it is interesting to note from *The Crockery Journal*, that Cincinnati is referred to as a growing industrial center in the manufacture of earthenware and queensware, the annual product of that city in the year 1874 being valued at \$300,000. Trenton is cited as the production center of much glass tableware but Wheeling, W. Va., was referred to as the extensive center of glass manufacturing, one of the largest firms employing 400 hands with a weekly payroll of \$4,000 and operating three ten pot furnaces. Several varieties of glass were made, including white porcelain glass for lamp shades.

In a yellowed copy of the *Journal* dated Jan. 22, 1875, is a long article covering the convention of Manufacturing Potters, "held in New York City, for the purpose of organizing a National Pottery Association and to provide a fine display for the Centennial Exhibition to be held in Philadelphia in 1876." A month later *The Crockery Journal* appeared as a weekly and in a comprehensive article on the history of pottery manufacture in the United States in the April 3, 1875, issue, is the statement that "One hundred and forty-eight kilns in seven states are in operation, producing ware valued at the rate of \$30,000 per kiln or a total valued production of \$4,440,000 per annum."

In May, 1875, *The Crockery Journal* opened a Boston office at 178 Washington Street and a Philadelphia office at 114 South Third Street and on June 10, the editorial office was moved to 30 Vesey Street, "to be in the more immediate center of the trade." But the rapid growth of the business necessitated again moving, May 11, 1876, to larger offices at 60 Church Street near Murray, where the *Journal* was published weekly for several years. As the paper continued to grow, larger quarters were again required and the office was moved to 150 Canal Street. For some time the printing department was continued at this address but was later moved to 49 West Broadway. On April 9, 1890, *The Crockery Journal* was offered space in the newly erected Gerken Building, at 92 West Broadway, where it occupied the same office for twenty-six years. With the death of Mr. Jaques in 1920 and the retirement of Mr. Whittemore, the publishing firm of Whittemore & Jaques, Inc., was succeeded by The Demarest Pub-

lications, Inc. As *The Crockery and Glass Journal* continued to expand greatly under the new management, a larger and more modern suite of offices was secured on the seventeenth floor of the Everett Building, 45 East 17th Street, and the *Journal* moved into the uptown crockery and glassware district, May 1, 1922, where the latch-string is always out.

Forty-eight years of progress. We are proud of the achievements of the past. *The Crockery Journal* filled an important niche in the trades it represented and as the ceramic industry has so greatly expanded during the two score and eight years, so have the opportunities of *The Crockery and Glass Journal* grown to serve a larger number of readers.

Today there are six hundred and eighty pottery plants in operation, representing a capital of \$133,315,940, paying \$59,640,000 annually in wages and with an output valued at \$108,350,220. Today, production of domestic ware is about twenty times larger than in 1874. The population of the country when the first issue of *The Crockery Journal* appeared was 38,558,371. Today it is more than 105,683,108. Because of this great increase in consuming power, and despite the great increase in domestic production, imports of china, earthenware and stoneware amounted to \$10,953,783 in 1920, compared with imports valued at \$6,015,945 in 1874.

The ceramic industry in this country is based on the solid foundation of a good and constantly increasing demand. It is a conservative industry, smaller and less spectacular than mining and the flowing gold of the oil fields, but it is a necessary industry and a relatively stable one and it is the ambition of *The Crockery and Glass Journal* to be of the utmost value in service to each and every one of its divisions.

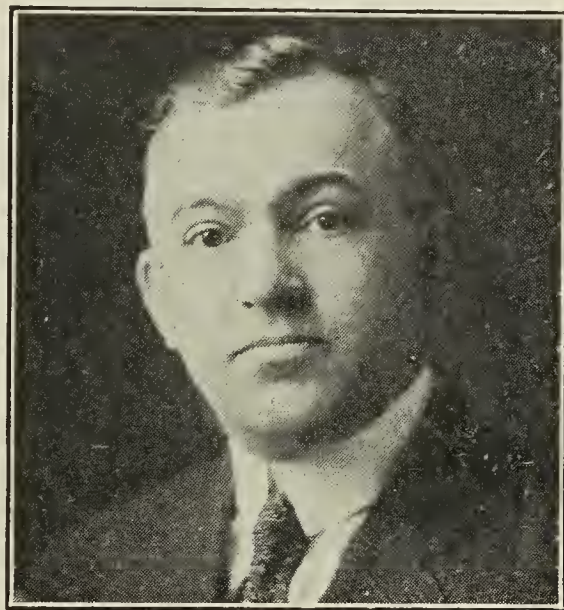
"THE CLAY-WORKER," A POTENTIAL FACTOR IN THE UP-BUILDING OF THE CERAMIC INDUSTRIES

BY J. E. RANDALL

The *Clay-Worker* founded in 1884 by Theodore A. Randall, its present editor and manager, is the pioneer clay trade journal in the world, and through the thirty-nine years of its existence has, through its wide circulation, been a potent factor in the upbuilding of the ceramic industries in this country. Recognizing the need and vast possibilities in educational ceramic work the *Clay-Worker* has held steadfastly from the first an editorial policy of publishing the best articles obtainable and through its various departments, such as Kiln Department, by the Light of the Kiln Fire, Recent Patents, Foreign Scrapings, Ceramic Corner, and Brickyard Sketches, ably edited by the experienced men in the trade, has given to the clayworkers of the nation a vast fund of ceramic literature. The majority of the best books in modern ceramic literature were published first serially in the *Clay-Worker* as is mentioned subsequently.

The editor of the *Clay-Worker* saw the possibilities in organized effort in the very beginning of his work, and hence in 1886, two years after the founding of the *Clay-Worker*, with the splendid support of D. V. Purington, he organized the National Brick Manufacturers' Association, and through the *Clay-Worker* (which was made the official organ of the Association) the clay products manufacturers of this country at that time were brought together in one harmonious body of men, and much was accomplished in placing the industry on the high plane it is today.

D. V. Purington was one of the most helpful associates in the early days of the *Clay-Worker*, and it is with his aid and that of such men as W. D. Richardson and W. D. Gates, that the first Ceramic School in the country was founded at Ohio State University. The *Clay-Worker* played its



JAMES E. RANDALL

part in supporting and establishing that and other ceramic schools by publishing articles by foremost men in the craft which encouraged the ceramic students and made them more eager for the higher ceramic knowledge.

In reviewing the past twenty-five years of effective work of the *Clay-Worker* the above has been mentioned to give the younger ceramists an idea of our earlier activities. Many valuable technical articles were published in the *Clay-Worker* long before 1898. We mention only two here: the series of William Waplington on "Chemistry for Clayworkers," starting May, 1892, and ending in 1897 (53 numbers), and "Hints on Brickmaking," by R. B. Morrison, starting in 1885 and ending in 1899, afterward revised and published in book form under the title of "The Brickmakers' Manual." Another book published about that time, and which is still in demand is Griffith's "Clay Glazes and Enamels."

The February, 1898, issue of the *Clay-Worker* contained in full the National Brick Manufacturers' Association convention paper of E. E. Gorton, of Terra Cotta, Ill., entitled "Experimental Work, Wise and Otherwise." The reading, discussion and publication of this paper which was editorially mentioned as an exceptionally able document planted the seed which grew and blossomed forth into the AMERICAN CERAMIC SOCIETY. Every annual and mid-summer meeting of the AMERICAN CERAMIC SOCIETY has been given a careful and exhaustive review in the columns of the *Clay-Worker* and everything possible has been done to coöperate with its officers, with the sole idea of advancing the ceramic industry in general.

To encourage the ceramic student, both in school and business life, the *Clay-Worker* has always published such technical articles as are

available, and has enlisted the aid of the best technical men in the industry. Hence, in the *Clay-Worker* of twenty-five years ago there appeared articles from the pen of such men as W. D. Richardson, Samuel Geijsbeek, E. E. Gorton, Heinrich Ries, Karl Langenbeck, H. A. Wheeler, Charles F. Binns, and A. V. Bleininger. "Artificial Pottery Bodies," by Samuel Geijsbeek; "Theory and Practice in Glaze Composition," by Charles F. Binns, and "English China Ware," by Heinrich Ries, written especially for the *Clay-Worker*, appeared in 1898. From that time on, due to the interest aroused by these articles, the *Clay-Worker* printed a great many especially prepared articles of much value to the ceramic industry, and reprinted important and valuable papers from the proceedings of the English Ceramic Society, also the AMERICAN CERAMIC SOCIETY and the German, French, British and other trade and technical journals. Of particular importance in this connection, was the paper on "Soaking and Curing Clay," by Otto Bock of Berlin, which with the discussion following same, appeared in serial form in the *Clay-Worker* during the year 1903, by special permission from the *Tonindustrie Zeitung*.

"The Use and Abuse of Clayworking Machinery," by F. E. Frey appeared in serial form during 1898 and 1899, and was very valuable to the clay industry, as were also the serials on "Artificial Dryers and Kilns," by L. C. Moore, "Fire Brick, Manufacture and Use," by Alfred Crossley and "Development of Hollow Block Manufacture," by E. G. Durant. Special articles, such as "Enameled and Glazed Brick," by S. Geijsbeek, "Clayworking in Denmark," "English China Clays," and "Clayworking in Greece," all three by Heinrich Ries, and "Utility of Art in Clay," by H. A. Wheeler, likewise appeared in 1898.

In 1900 E. E. Gorton contributed two important articles, "Defects of Glazes" and "Secret Information." Karl Langenbeck's first contribution was "The Cause of Variations in the Firing of Kilns and the Remedy for Same." Other important articles of that year were "Crowns of Kilns" and "Seger Cones," by D. W. Stookey; "Kaolins and Fire Clays of Europe," Heinrich Ries; "Chimneys and Riddle Bottom Kilns," G. S. Tiffany; "The Royal Saxon Porcelain Manufactory," Robert Grimshaw; "Exact Instruments for the Clayworker," "Some Costly Bits of Experience," L. C. Moore; and "The Modification of the Tunnel Kiln as Constructed by Mueller and Pfeiffer."

In 1901, the more important articles were "Colorado Clay Deposits," by S. Geijsbeek; "Pulverized Coal as a Fuel for Burning," and "Light and Heat," both serials by F. E. Frey. The latter article continued through 1902 and 1903. "An Expedient for Maintaining Constant Temperature through the Process of Salt Glazing Clay Ware," I. A. Williams; "Plasticity of Clays," Edward Orton, Jr.; "Georgia's Clay Industries and Clays" (serial), "Notes on Flashing," A. V. Bleininger; "A Pacific Coast Clay-

working Plant," E. E. Gorton, and "The Birth of English Porcelain," by Charles F. Binns were published in 1901.

In 1902, "The Foreign Scrapings" department was inaugurated under the editorship of George J. M. Ashby, who translated and briefed the more important articles appearing in foreign publications. Upon the death of Mr. Ashby, Samuel Geijsbeek became the editor of the department and has rendered most valuable service to the ceramic industry in this connection. "Opportunities of the Young Clayworkers of the Twentieth Century," D. V. Purington; "Experiences in Burning with Oil," W. D. Gates; "Clayworking Industries in Germany," A. V. Bleininger; "Lamination in Clays," George S. Tiffany; and the serials "Talks on Burning;" "Clay Dust" and "The Modern Clayworker," and "Plant Management and Plant Problems" were the most worthy articles in 1902.

In 1903, William Waplington contributed a valuable serial, "Theory of Draft and Chimney," which continued through that year and 1904, as well as a serial on "Theory of Drying." Other serials of that year were "Brickyard Experiences," by L. C. Moore, "Burning Brick with Producer Gas," by J. J. Koch, "Manufacture of Fire Brick," H. J. Quandt and "Brick and Bricklaying," by Owen B. Maginnis; "Slag Brick and Cement," A. V. Bleininger; "Watersmoking and Whitewash," J. J. Koch, "Special Refractories from Primary Kaolin" also appeared that year.

"The Rôle Played by Iron in the Burning of Clay Wares," by Prof. Edward Orton, Jr., was printed in full in 1904; "Kiln Atmosphere," "Salt Glazing," "Draft and Heat" and "The Cause of Crazing of Sewer Pipe," were four articles by Anton Vogt. The serial "Chemical Formulas as Used by Clayworkers," and such articles as "Relative Value of Fuel," by J. J. Koch; "Useful Properties of Clays," Harvey W. Wiley; and "Behavior of Iron in Clay When Burned to Viscosity," by George C. Matson, also appeared in 1904.

The year 1905 is credited with two fine serials by W. D. Richardson, which were afterward put in book form, and are still in demand; namely, "Burning Brick in Down Draft Kilns" and "Drying Brick."

"The Possibilities of Porcelain," C. F. Binns; "Trenton, the Staffordshire of America," J. Homer Stover; "Economy of Producer Gas for Burning Clay Ware," Lemon Parker, and the serials "Economical Generation and Use of Steam," W. D. Richardson, and "Fuel Values," J. J. Koch, appeared in 1906.

"The Effect of Heat upon Clays," by A. V. Bleininger, was a serial running through 1907 and 1908, that was later put in book form and had a tremendous sale. "Crazing of Glazed Ceramic Products," Karl Langenbeck, and "Tests Regarding the Melting Stages of Seger Cones" appeared in 1907.

In 1908, Walter A. Hull wrote a series of articles for the *Clay-Worker*

covering "The Use of Dampers" in two parts, "The Question of Draft," "Different Methods of Burning," and "Economy of Small as Compared with Large Plants;" Samuel Geijsbeek contributed "The Tunnel Kiln System in Use in the German Porcelain Industry," and W. D. Richardson, "The Layout of Round Kiln Crowns." "Use of Barium Compounds," Ellis Lovejoy, was reprinted from *Transactions of the American Ceramic Society*; "Controlling Dryers and Kiln Operations," A. V. Bleininger; "Making Front Brick without Repressing," R. T. Stull; and "The Manufacture of Enameled Brick," Ernest Hardy, were published that same year, having been read before the Illinois Clayworkers' Association.

"Gas Producers and Gas Fired Continuous Kilns," by J. J. Koch, was the most important of the serial articles in 1909. However, there were many valuable short articles including "The Use of the Draft Gauge," in two parts, and "Function of the Test Kiln," Walter A. Hull; "Sanitary Pipe Making," H. W. Hardy; "Rough Face Brick," Ellis Lovejoy; and "Air under Pressure as Compared with Natural Gas." Reprinted papers were "The Preparation of Surface Clays" (two parts), A. V. Bleininger; "Pyrometric Cones," J. M. Knoté; "Method of Overcoming the Sulphur Problem," H. B. Wells; and "Salt Glazes of Surface Clays," L. E. Barringer.

"Economy in Brickyard Construction and Operation" was a serial by Ellis Lovejoy, started in 1909 and run through two years; was later published in book form, and is still in demand.

The 1910 volume of the *Clay-Worker* contains many fine articles, such as "The Manufacture of Clay Pots;" "Making Sanitary Ware and Salt Glaze Brick in England," Frank Hardy; "Importance of Labor Saving Devices," J. D. Pratt; "A Modern Pottery, Its Construction, Operation and Products," H. E. Ashley; "Japanese Ceramics," H. Shugio; "Polychrome Architecture from View Point of Clayworker," H. C. Mueller; and "Some Problems of the Clay Working Industry," Dr. I. A. Holmes. Convention papers, "A Lubrication Die for Hollow Ware," R. T. Stull; "Combustion of Fuel and the Application of Heat in Kilns," A. V. Bleininger; "The Function of Lime in Clays," A. V. Bleininger; and "Notes on the Manufacture of Enameled Brick," R. T. Stull; The Department of Recent Patents was inaugurated in 1910, and is still continued, giving a list of all patents of interest to clayworkers.

The articles of chief interest to ceramists in the 1911 volume of the *Clay-Worker* are "Making High Potential Porcelain Insulators," "Removal of Overburden by Hydraulic Sluicing," Paul Beer; "American and English Clay Methods," H. W. Johns; "Blistering of Stoneware Glazes;" "Melting Point of Clays" and "Fuller's Earth," Ellis Lovejoy. That year was also reproduced the splendid Bulletin by A. V. Bleininger, U. S. Bureau of Standards, "Effect of Preliminary Heating Treatment upon the Drying of Clays," in a seven part serial.

The 1912 issues of the *Clay-Worker* contained such articles as "Roofing Tile," a serial, which continued into 1913, by W. G. Worcester; "How Much Heat to Dry a Thousand Brick," a serial running through a part of 1913, by R. B. Hoehne; "Choice of a Kiln," W. D. Richardson; "Points of Construction and Operation of Lubricating Dies," R. T. Stull; "Pottery Making, American and English," C. F. Binns; "Gas from Gas Producers, and Its Combustion," J. J. Koch; "Drying of Clay Products," I. M. Justice; "Impressions of Clayworking Methods in Europe" (serial), A. E. Eaton; and "Making Terra Cotta Columns," H. W. Johns. Of even greater value this year was the series of articles of Ellis Lovejoy on "Drying Clay Wares," which continued through 1913, 1914 and 1915, was afterward published in book form, and has enjoyed an extensive sale throughout this country and Canada, being acknowledged a text-book on that subject.

The 1913 volume contains "Whitewash, Cause and Remedy," "How to Salt Glaze Sewer Pipe" and "Burning Brick in Common Up-Draft Kiln" (two parts), all by J. J. Koch. "Design of a Tile Plant with a View to Economical Construction and Operation," C. B. Harrop; "Harvested Thoughts on Drying Clay Ware," I. M. Justice, and "Factory Costs," J. L. Childs. The last three were convention papers.

In 1914, the *Clay-Worker* inaugurated the "Build with Brick" campaign, which scattered the slogan "Build with Brick" on signs, both metal and cardboard, all over the country and did much to arouse the brickmaking fraternity to the value of advertising and the people generally to the real value of burned clay products. The same year the *Clay-Worker* suggested the idea of holding prize competitions in the schools to gain additional publicity and start the younger generation to thinking in terms of clay products. "The Manufacture of Sewer Pipe" was an important series of articles by Anton Vogt which appeared in 1914. Other articles of interest to ceramists were "Economy of Continuous Kilns," William A. Butler; "Burning with Gas," J. J. Koch; "Burning Flash Brick;" "The Underwood System of Burning;" "Lamination, Its Causes and Remedy;" and "On the Burning of Rough Texture Shale Brick," Walter A. Hull, which was reprinted from *Transactions of the American Ceramic Society*.

The 1915 issues of the *Clay-Worker* contained "The Manufacture of Electrical Conduits;" "Leadless Glazes Used in Denmark;" "Things a Lump of Coal Can Do;" "The Value of Experiments;" "When Is a Kiln a Kiln;" "Dryer over Continuous Kiln;" "Ceramics in Illinois;" "Graphite Clay Products;" "Clay Products as an Engineering Material" (two parts), A. V. Bleining, Bulletin of Bureau of Standards; "The Legal Interpretation of the Word 'Vitrified' as Applied to Ceramic Products," Prof. Edward Orton, Jr., from American Society for Testing Materials; "Purification of Clays," A. V. Bleining, Convention paper.

In the year 1916, there appeared "The Problem of Pottery Clays;"

"Some Views of Clay Burning;" "Blasting Down Shale and Plastic Clays;" "Analyzing Clay and Physical Testing;" "Glazing Drain Tile;" "Washing of Clays," J. J. Koch; "Flashing Brick," Anton Vogt; "Practical Clay Testing;" A. Malinovsky; "Burning and Salt Glazing Tile," J. J. Koch; "Practical Tests," F. N. Menefee; "Future of Ceramic Education in America," Prof. Edward Orton, Jr., New Jersey Convention paper; "A Study of Atterburg Plasticity Method," C. S. Kinnison, U. S. Bureau of Standards Bulletin; "Properties of Some European Plastic Fire Clays" (four parts), A. V. Bleininger, and H. G. Schurecht, Bulletin U. S. Bureau of Standards. "The Manufacture and Use of Compounds of Barium," Emley and Young, U. S. Bureau of Standards; "Experiments to Overcome Scumming and Improve the Color of Brick," A. E. Williams, *Transactions of the American Ceramic Society*; "Production of Finer Grades of Stoneware from Illinois Stoneware Clays," R. R. Danielson for Illinois Convention.

Beginning in 1916 and continuing through 1920, there appeared in the *Clay-Worker* the most complete and pretentious serial article ever written for the clayworking craft, that of "Burning Clay Wares," by Ellis Lovejoy. The second edition has just been issued, and the book has been accepted as a text-book, being generally considered the best, most thorough and practical volume ever published for the ceramic industry.

During the year 1917, there appeared, "Plant Management (a serial), R. B. Hoehne; "Richardson Continuous Kiln," H. C. Arnold; "Producer Gas Fired Tunnel and Compartment Kilns," R. H. McElroy; "American Haigh Kiln," Lambert Haigh; "Economy in Kiln Crown Building;" "Rectangular versus Round Kilns;" "Ceramic Engineering," L. E. Barringer; "Preparation of Clays, Mining, Drying and Proper Mixing," W. W. Swengel; "An Improved Clay Dryer," W. W. Swengel; "Factors of Depreciation and Their Importance in Figuring Costs," J. E. Randall; "Casting Heavy Clay Products," Frank Riddle, U. S. Bureau of Standards; "Relation of Efficiency of Up-Draft and Down-Draft Kilns," J. D. Pratt, for the Wisconsin Convention; "Brickwork Tests and Formulas" (two parts), H. Kreuger—translated by G. Wson Cronquist; "Pug Mill, Its Use and Abuse," Robert Twells, U. S. Bureau of Standards; "Notes on the Crucible Situation," A. V. Bleininger.

"Report of Coöperative Brick Pier Investigation between National Brick Manufacturers' Association and the United States Bureau of Standards," J. G. Bragg, was published in 1918, as was "Economic Methods of Heating Clay Storage Sheds," C. Hartsell; "Strength of Sewer Pipe;" "Waste Heat from Continuous Kilns," W. D. Richardson; "Importance of Structure in Refractories," F. H. Riddle; "The Fuel Value of Various Coals, Oils, and Producer Gases," O. L. Kowalke; "Standard Tests of Refractory Materials," F. H. Riddle; "Suggested Means of Saving Fuel;" "Classification of Refractories," F. H. Riddle; "Hollow Tile as a Factor in

Fire Prevention," Walter A. Hull. "Fuel Economy in Burning Clay Products," A. V. Bleining and A. F. Greaves-Walker, U. S. Bureau of Standards. "The Automatic Control and Measurement of High Temperatures," R. P. Brown, Faraday Society; "Advantages of Clay Storage and a Description of a Successful Installation," Frank H. Riddle, *Transactions of the American Ceramic Society*. "Recent Developments in Ceramics," A. V. Bleining (2 parts), Institute of Metals.

Among the articles of importance in the year 1919, were "Resistance of Clays;" "Manufacture of Fire Brick in England," D. V. Lowe; "Industrial Research;" "Magnesite in Refractory Work;" "Slags and Their Relation to Refractories," F. H. Riddle; "The Use of Refractories;" "Hot Blast Stoves;" "Basic Refractories for the Open Hearth," J. Spotts McDowell and Raymond M. Howe; "Designing of Factory Layouts for the Clay Industries," T. W. Garve, *Transactions of the American Ceramic Society*. "The Work of the Ceramic Experiment Station," R. T. Stull, United States Bureau of Mines; "Notes on Flow of Clay through Hollow Ware Dies," G. D. Morris, *Transactions of the American Ceramic Society*.

In 1920, the *Clay-Worker* printed "Pointers on Plant Management" (serial), W. D. Richardson; "To Determine the Quantity of Brick in a Circular Kiln Crown;" "Manufacture of Spark Plugs;" "Dimensions of Round Down-Draft Kilns;" "Fuel Economy in Coal Buying;" "Equalization Tables," by Ellis Lovejoy; "Pottery Making in Japan;" "Some Causes for Fire Brick Failures;" "An Exemplary Porcelain Insulator Factory;" "Refractory Oxides on Which Progress Depends;" "Storage and Handling of Raw Clays," T. W. Garve, *Transactions of the American Ceramic Society*.

In the 1921 volume of the *Clay-Worker*, we find such articles as "Observations Taken from Some Railroad Tunnel Kilns;" "Modern Development of the Direct Fired Type of Railroad Kiln;" "Modern Brickmaking in South America" (two parts); "Temperature at which China Ware is Burned;" "The Muffle or the Direct Fired Tunnel Kiln;" "Tunnel Kiln Truths;" and "The Tunnel Kiln in the Brick Industry."

The above compilation of titles is but a small part of the ceramic literature found in the *Clay-Worker* during these past twenty-five years. We have not included either the great mass of valuable material to be found in the reports of the National Brick Manufacturers' Association convention published every year. Nor are other articles mentioned which have appeared in the various departments, which are handled by capable writers, in the interest of the heavier clay products, such as paving brick, hollow ware, drain tile, etc. Therefore, the above gives but a slight idea of the real value of the *Clay-Worker* to the clay products manufacturers of the nation.

Theodore A. Randall, president of T. A. Randall & Co., publishers of the

Clay-Worker, is the editor and manager of the magazine, and in token of his work and efforts, both personally and through the columns of the *Clay-Worker* in behalf of the AMERICAN CERAMIC SOCIETY, was made a life member of that organization at the St. Louis convention in 1907.

James E. Randall, Secretary-Treasurer of T. A. Randall & Co., and junior editor of the *Clay-Worker*, is an active member of the AMERICAN CERAMIC SOCIETY.

"BRICK AND CLAY RECORD:" ITS HISTORY

BY F. L. STEINHOFF

Just call to mind any industry, the steel, power, chemical, automobile, engineering or electrical, and if you will follow its history and that of the business paper identified with it, you will notice a marked similarity in the progress and development of each. There is this one constant point of difference, however. The successful business paper is always a step ahead of the progress of its industry. The business paper does not keep pace with the industry but the industry follows in the light of the business paper's teachings—for this is one of the prime reasons for its existence.

As important as the church and school are to the nation's spiritual and cultural development, just so essential is industrial publishing to American industry. "There is no teacher whose work is more essential in the progress of our commercial and industrial world," said E. N. Hurley, former head of the United States Ship Building Corp., speaking of the industrial press, "no reporter whose news is of more permanent interest to its readers. It is a most valuable adjunct of industry and is a necessary and important tool to the manufacturers, the merchants and business men in general."

The point of these statements may be summed up as follows: If you want to know the history and enterprise of a business paper, just note what development has taken place in the industry itself.

Many of you have turned through the pages of such highly esteemed publications as the *Iron Trade Review* and *Iron Age* in the steel industry, *Power and Power Plant Engineering* in the power plants, *Chemical Age* and *Chemical and Metallurgical Engineering* in the chemical industries. Their leadership in gathering and spreading information of special interest to their readers, their functions as a clearing house for trade ideas and business policies in their field, their promotion of the interests and technical development in the industries they serve—these energetic, persistent and consistent activities were largely responsible for the progress of their respective industries.

Just as other business papers have had a prominent part in the unfolding of their industries, so has *Brick and Clay Record* played a similar rôle in the technical as well as business advancement in the ceramic industries; particularly in those branches whose products enter into the construction of buildings, pavements, drainage systems, and iron and steel furnaces.

Thirty years ago clay products were largely made by processes as crude as those in use twenty centuries before. This is not true today and, while the surface of development in the clay industry has barely been scratched, one cannot express aught but amazement at the remarkable development that has taken place in recent years. It is an astounding fact that certain branches of the clay industry have made greater progress in the last thirty years than in the previous three thousand. The mechanical setting of brick, mechanical loading of brick onto motor trucks, car tunnel kilns, motorization of the industry, automatic stokers on kilns, humidity dryers, shale planers, conveying systems for unloading kilns, automatic brick machines, are only a few of the many new labor saving and cost cutting ideas that have come into use in the past thirty years.

It was during these same thirty years that *Brick and Clay Record* was developing from an infant magazine into a publication whose statements carried international weight. Its standing in the industry which it serves is unique in that its ratio of readers to the number of establishments is as high, if not higher, than that of the highest ranking business paper in any other field. This extremely high measure of good-will which it has acquired is directly due to the progressive stand it has always taken in the interest of the industries it serves.

It would be easy to fill a book with the reasons why *Brick and Clay Record* has played such an indispensable part in helping the clay products industry to achieve its present high plane of development. Briefly, a few of the special enterprises and activities it has fostered are summed up below:

Brick and Clay Record was first to recognize the lack of proper merchandising methods in the clay products industry, which was the cause of thousands of dollars loss annually. Ideas for better distribution were outlined and sponsored.

It has always fought for and advocated wide publicity instead of silence for all clay products as a weapon against the great inroads made in its market by substitute materials. The wisdom of this course was appreciated and now there is hardly a clay product which does not broadcast its message throughout the entire country.

Wherever an appropriate field existed for a trade association *Brick and Clay Record* has encouraged the formation of such associations even to the extent of using its own funds to assist organization. The folly of leaving one organization to take care of the interests of all the various

products was finally recognized some years ago and strong associations formed in each separate branch of the industry. Tremendous benefits have resulted from this reorganization of the industry.

The disreputable practice of price cutting as well as profiteering has been vigorously discouraged.

Brick and Clay Record has always admonished manufacturers that substitute materials would take away their markets if cost, and therefore prices, were not kept low—to this end it has persistently inspired plant betterments and blazed the way to improved methods. Its columns have been a forum for the discussion of important problems and a clearing house for ideas from every part of the world.

Editorial representatives of *Brick and Clay Record* have visited the most distant parts of the country to investigate and give light to the latest developments in machinery, equipment and manufacturing methods, thus enabling the entire industry to profit by the highest development of any part.

The establishment of standardized shapes and sizes has always been fostered and coöperation whole-heartedly and liberally given.

Realizing that an over-capacitated industry is always highly unstable and unsound, *Brick and Clay Record* has invariably discouraged the construction of new plants at points where neither material nor market existed.

To eliminate as much as possible the enormous mortality rate of 11% in the clay industry, the dire need for knowing costs has been urged consistently. Good cost systems which have been described in its columns have enabled manufacturers to establish fair prices.

As a distinctive assistance, aside from its regular service, *Brick and Clay Record* has counselled and informed manufacturers on thousands of technical, sales, accounting, legislative and other important problems and policies.

To aid in the stabilization of the market *Brick and Clay Record* has published from time to time the current prices of many of the commodities manufactured in the field.

News of what the various concerns in the industry are doing in the way of installing new machinery, adopting new methods of production, sales, accounting, and so forth, has been a distinct help to brother craftsmen in the clay products industry by providing a source of contact with the industry.

Brick and Clay Record has always been an independent paper, unprejudiced and unbiased, has never permitted itself to be officially adopted as the mouthpiece of any organization but it has been endorsed by practically all of the many trade and technical associations represented in the clay products industry.

The germ of thought of industrial research, such as is now being carried on by four prominent clay product associations and collaborated in by the AMERICAN CERAMIC SOCIETY, the United States Bureau of Standards and the United States Bureau of Mines, found its origin in the editorials and preachment of *Brick and Clay Record*.

Some of the best books published on American methods of producing ceramic ware have been published by *Brick and Clay Record* from time to time and are now found as a standard equipment on nearly all progressive plants. "How to Analyze Clay," by Holden M. Ashby, published and distributed by *Brick and Clay Record*, was one of the first helpful books for the clay manufacturer who desired to know methods that could be adopted to determine the value of his clays.

"Clay Working Problems," published by *Brick and Clay Record* in 1915, was a selection of 101 questions from more than 500 addressed to the editorial office of *Brick and Clay Record*. These were questions asking for practical information on vital and practical problems daily confronting the manufacturer. Questions were answered by men who were considered authorities and the problems, together with their answers, published in book form. It has been a valuable contribution because of its unique and very practical character, to the literature on clay manufacture.

"Scientific Industrial Efficiency," written by Dwight T. Farnham and published in 1917, has been acclaimed as one of the best books ever published for a special industry. Its author is one of the most renowned industrial engineers in America and not only is a member of the AMERICAN CERAMIC SOCIETY, but is well known throughout its entire organization.

"Clay Plant Instruction and Operation," by A. F. Greaves-Walker, published by *Brick and Clay Record* in 1919, has saved thousands of dollars for prospective and veteran clay manufacturers throughout every section of this country and Canada. Mr. Greaves-Walker, previous to preparing this volume had a broad experience in the manufacture of nearly every clay product in a wide variety of sections in both the United States and Canada. Both his diversified experience and ability has contributed to make this volume one of indispensable aid to the manufacturer.

"Clay Products Cyclopedia," published in 1922 is the most recent product of *Brick and Clay Record*. It contains 752 definitions of processes, materials and pieces of equipment of direct interest to clay manufacturers. It also contains a statistical section including the most vital and essential data required in the manufacture of clay products and a catalog section giving descriptions of the most important equipment and machinery required in the industry.

This book was the first attempt ever made to compile in a brief and compact form, the wealth of information pertaining to clay products manufacture which is scattered in the many journals, magazines, books and

catalogs published on the subject and the knowledge of those of long experience in the varied fields of clay manufacture.

Brick and Clay Record itself is the result of the amalgamation in 1910 of two publications, "Clay Record" and "Brick." "Clay Record" was established in 1891 and "Brick" three years later in 1894. In uniting, these two journals were placed on a better basis. In the early days of the publication only three persons gave their full time to its editing, circulation and business. At the present time, because of its enlarged activities, twenty-one persons are required in its editorial, circulation and business departments besides twenty men scattered throughout various sections of this country and two in foreign countries, gathering news and other data of special interest to the manufacturer of clay ware. From a paper of purely local interest its subscription list has extended to include readers in nearly every country in the world; its articles are often reprinted in many foreign journals.

Brick and Clay Record has made a host of friends in the industry; it is proud to report that its friends have increased and become more intimate each year. It is only natural in publications that some disagreement in policy would manifest itself at times, but this has occurred so infrequently that it has been almost negligible.

However, the friendships and esteem that *Brick and Clay Record* has built in the industry were not established upon the personalities of any of its personnel, but upon the more sound and business-like basis of its value as an institution and a source of constructive ideas and policies. For the same reason the paper has constantly grown in esteem and influence.

In volume No. 1 of "Brick" an editorial stated "The magnitude and extent of the clay industries combined to constitute one of the most important business interests of this country, so that with a constant improvement in methods and enlargement of scope there are created new needs and requirements. To these advanced ideas 'Brick' will be especially devoted. It will be at once practical, progressive and entertaining, and it will be our constant pleasure to make each succeeding issue better and more attractive." As it has in the past, *Brick and Clay Record* will continue in the future to subscribe to these ideals and to devote its interests to making "each succeeding issue better and more attractive."

"THE GLASS WORKER" AND "CHINA, GLASS AND LAMPS"

BY JOHN M. HAMMER

Two weekly journals published in Pittsburgh for the past 40 years in the service of branches of the ceramic industry are *The Glass Worker* and *China, Glass & Lamps*. The first, as its name implies, is dedicated to the

glass industry in all its departments. *China, Glass & Lamps* is a medium standing between the general ware and art pottery fields and the glassware industry and those who distribute such wares in various ways. The history of these journals is similar to that of most other trade organs which have survived the strenuous competition of 20 years or so ago.

The Glass Worker in its more than 40 years has undergone several changes of name. In striving to keep pace with the growing and changing glass industry, it also has changed in appearance and editorial content, attempting to meet the present needs of the industry it serves insofar as its editors sense those needs. Being a trade journal, it tries today to be of service as fully as it can to all the branches of the glass industry. The technical side is neither lost sight of nor centered upon to the extinction of regular trade news.

The two journals named are published by the Commoner Publishing Co., chartered under the laws of Pennsylvania. *The Glass Worker* is issued each Saturday and *China, Glass & Lamps* on Monday of each week.

In addition to the publication of two journals serving what are really two distinct fields, the publishers, through *The Glass Worker*, have given to the glass industry three books of a practical technical nature which have a world-wide circulation. The latest, "American Glass Practice," written by Harry Bastow, a man of experience as a glass manufacturer and consultant, is a treatise covering the practical side of glassmaking. Modern problems are discussed in the light of experience and practical formulas are presented. The book is intended for the intensive use of practical glassmakers. "Chemical Analysis for Glassmakers" by Edward C. Uhlig, B.S., contains methods of analysis for raw materials that enter into the manufacture of glass and other products based on silicates. It is illustrated and is planned for the practical chemist. "Elements of Glass and Glassmaking" by B. F. Biser, is for the practical glassmaker and includes facts and formulas of use in the manufacture of window and plate glass, containers, flint glass and colored glass.

China, Glass & Lamps covers broadly the china and porcelain tableware and utilitarian pottery fields and table and ornamental glassware with special reference to their distribution at both wholesale and retail. Virtually unaided, it fought for many years for adequate tariff protection for American dinnerware manufacturers. This and the purveying of technical and semi-technical news to the general ware pottery industry have been its largest contact between the producer and the seller.

The business management of the journals for many years has been in the hands of J. G. Kaufmann well known to glass and pottery manufacturers. At present, the editorial management of the two journals is in charge of John M. Hammer, a trained newspaperman. He specializes on the

pottery and glassware industries. George J. Eibel, Jr., has been connected with glass industry trade journals for nearly 30 years and is in direct editorial charge of *The Glass Worker*. He has a wide acquaintance in the glass industry and a knowledge which only 30 years of the closest contact can give. A veteran of both journals is Henry W. Gauding, formerly in editorial charge of each of the weeklies. An experienced glass man, Mr. Gauding gives a practical touch to the editorial staff.

"CHEMICAL AND METALLURGICAL ENGINEERING"

BY ALAN G. WIKOFF

About three years after the foundation of the AMERICAN CERAMIC SOCIETY, a small group of men who had been active in the organization of the American Electrochemical Society met in Philadelphia to consider the question of establishing a technical journal devoted to the interests of the rapidly developing electrochemical industry. As a result of this conference, the Electrochemical Publishing Company was formed, with Dr. Joseph W. Richards, late professor of metallurgy at Lehigh University, as president, and Dr. E. F. Roeber was chosen editor of the new monthly, *Electrochemical Industry*, which made its first appearance in September, 1902.

From this the present *Chemical and Metallurgical Engineering* has developed by a series of logical steps. It was soon found that presentation of developments in electrochemistry and electrometallurgy in their proper perspective involved consideration of allied industrial fields. The enlarged editorial scope was indicated in 1905 by a change in name to *Electrochemical and Metallurgical Industry*. Further extension was reflected in another change in 1910 to *Metallurgical and Chemical Engineering*. In 1912 the entire stock of the Electrochemical Publishing Company was acquired by the McGraw Publishing Company. Greatly increased service to the industry was made possible by semi-monthly publication which began in September, 1915. During the War, a great impetus was given to the profession of chemical engineering and it was thought advisable to emphasize this development by rewording the title in July, 1918, to *Chemical and Metallurgical Engineering*. A little more than a year later—in October, 1919—publication was placed on a weekly basis in order that it might be possible to give readers more timely information regarding important happenings. During the twenty years of its existence, *Chemical and Metallurgical Engineering* has witnessed many profound changes in the industries which it serves and because of its ability to sense these changes and to assist in guiding them in the right direction, it has been able to maintain its leadership in this field.

This outline would be incomplete without brief mention of the McGraw-Hill Company, since Mr. McGraw was interested in *Chemical and Metallurgical Engineering* from the start. This company resulted from the consolidation of the two leading engineering publishers, the McGraw Publishing Company and the Hill Publishing Company.

James H. McGraw gained his first experience in the publishing business with the American Railway Publishing Company of New York, then owner of *Street Railway Journal*. This periodical was acquired and renamed *Electric Railway Journal* by Mr. McGraw in 1888, after the dissolution of the publishing company. An electrical paper purchased in 1896 was consolidated with two others acquired in 1899 to form the *Electrical World*. To control these enterprises the McGraw Publishing Company was incorporated in 1899, with Mr. McGraw president and controlling stockholder. In 1902 *Engineering Record* was added and during the same year Mr. McGraw lent his aid and influence to the foundation of the Electrochemical Publishing Company, the development of which has already been discussed. *Electrical Merchandising* and *The Contractor* complete the list.

John Alexander Hill became a publisher with the acquisition of *Locomotive Engineering*, after having been several years on its editorial staff. Under his direction the publication became a success, but it was sold and in 1902 the Hill Publishing Company was formed by consolidation of the American Machinist Press, publisher of the weekly, *American Machinist*, and Power Publishing Company, which owned the monthly, *Power*. Subsequent additions include: *Engineering and Mining Journal*, 1905; *The Engineer*, a semi-monthly, consolidated with *Power* to form a weekly in 1908; *Engineering News*, 1911; *Coal Age*, a weekly, started in October, 1911, and consolidated with *Colliery Engineering* in 1915.

Although the book companies affiliated with these two organizations had combined in 1909 to form the McGraw-Hill Book Company, consolidation of the two publishing firms did not take place until after the death of Mr. Hill, 1916. At the present time the company publishes thirteen engineering and industrial journals—eleven in New York, one in Chicago, one in San Francisco and the European edition of *American Machinist*, in London.

After the death of Dr. Roeber in 1917, Mr. H. C. Parmelee, who had been western editor since 1910 (with the exception of one year during which he served as president of the Colorado School of Mines) became editor. Under his direction the editorial staff has kept pace with the development of the broader editorial scope, and it is now by far the largest of any periodical in this field, numbering eleven men. They are: H. C. Parmelee, editor; Ellwood Hendrick, consulting editor; Ernest E. Thum, associate editor; J. S. Negru, managing editor; Alan G. Wikoff, R. S. Mc-

Bride, Sidney D. Kirkpatrick, A. E. Buchanan, Jr., Graham L. Montgomery, Charles Wadsworth, 3rd, Charles N. Hulburt, assistant editors. From the very nature of the field covered, it is evident that *Chemical and Metallurgical Engineering* has always been directly interested in certain phases of the ceramic industry. Indeed, the first issues of the paper contained information regarding processes used at Niagara Falls for the manufacture of electrochemical products which are now widely used as refractories. Being in close contact with users of refractories, it was possible to encourage research and process improvement in this field by supplying the true facts regarding the behavior of refractories under service conditions. With the possible exception of boiler installations, there is hardly a field for the application of refractories which is not treated in *Chemical and Metallurgical Engineering*.

Other ceramic topics which have received considerable attention are: glass technology and research; manufacture and application of chemical stoneware; production of chemical porcelain; fused silica.

Within recent years, particular attention has been given to the meetings of the AMERICAN CERAMIC SOCIETY, complete reports of these being prepared by one of the editors who is a member of the SOCIETY. Plants visited during the summer meetings have also been written up. It is felt that this work has been helpful in bringing the accomplishments of the AMERICAN CERAMIC SOCIETY and the problems of the ceramic industry to the attention of a diversified group of interested technical men.

Turning to the books which have been published by the McGraw-Hill Book Company (which, it should be noted in passing, maintains an organization and offices separate from, although affiliated with, the publishing company) much the same condition is found to exist that was referred to in connection with the journal. With the exception of Havard's "Refractories and Furnaces" most of the books have dealt with ceramic materials from the point of view of service conditions. Here again the field has been thoroughly covered particularly as regards refractories. Without going into detail to the extent of attempting to cite the individual books, it is evident from the following list of subjects that few fields of application have lacked consideration: Boilers; gas producers; coke ovens; electric furnaces; general metallurgy; blast furnace construction; metallurgy of iron and steel; smelting of copper, lead, zinc and tin; cement manufacture; petroleum refining.

In closing this brief review, it may be stated that the editorial policy of *Chemical and Metallurgical Engineering* calls for still closer contact with the ceramic industry so that increased service may be rendered in the years to come.

"THE GLASS INDUSTRY"

BY J. B. KRAK

The Glass Industry claims the distinction of being the first monthly technical publication (other than official organs of technical societies) devoted to glass technology, manufacturing practice, raw materials, factory management and related subjects, and conducted in accordance with modern publishing practices. This claim can be made only by a narrow margin. The first issue of *The Glass Industry* appeared in November, 1920. Two months later a similar publication in the French language was started in Belgium.

Indeed the time was ripe for the establishment of a technical paper concerned exclusively with glass manufacturing. The past twenty years have witnessed all over the world a tremendous expansion of every line of industry. This applies especially to the United States. Coincident with this great industrial development has been the growth of industrial publishing. Here also the United States has led. In this country the technical papers have become the acknowledged leaders of the industries with which they are identified. Official recognition was given to the technical press during the War when editors of engineering publications were frequently called upon to confer with heads of the various government agencies. Some of the prominent men in the industrial publishing field were drafted for war service and rendered invaluable assistance in solving the many technical and economic problems of that period.

Glassmakers have realized for some time that there was a need for a technical journal in their industry. They frequently voiced the opinion that the glass industry would derive substantial benefits from a periodical conducted upon modern lines, treating principally of the technical and practical manufacturing problems of glassmaking and giving to this phase of the industry the same earnest attention and study that similar problems in other industries receive from their journals.

The publishers of *The Glass Industry* recognized the unusual opportunity of establishing a technical paper in a field practically untouched. They realized that the glass industry is at the beginning of a new era of expansion. When confronted with the demand for a modern technical publication to cover the glass industry they accepted the challenge.

The Glass Industry, now beginning the third year of its existence, has met with the cordial responsiveness of practically all who have become acquainted with its plans and purposes. Glass makers have quickly appreciated the value of a publication having the object to provide a medium of information through which they can keep themselves abreast of the latest developments, invention and thought in glass engineering and research, the best practice in melting, annealing and other operations.

The Glass Industry stands for adequate scientific control of the various

processes of glass making. It aims to publish the opinion of experts on tank design and operation, gas producers and fuel problems, batch ingredients, refractories and the numerous other subjects related to the problems, large and small, with which the glass manufacturer is at all times confronted.

The Glass Industry is independent of all special interests. It is controlled only by its publishers, men of long experience in the technical publishing field. Its work is to collect from every reliable source all the useful ideas and accurate information available and to present them to its readers in plain understandable fashion. Its columns are open to all who have any useful facts or ideas to offer to their fellow workers in glass.

The publishers and editors subscribe to the code of ethics that has been adopted by the national associations of business publications and industrial editors. They are pledged to consider first the interests of the subscribers, to present the news of the industry free from personal bias and to determine the policies of the paper independently of advertising considerations.

Having established *The Glass Industry* as a medium of technical information and discussion, the publishers feel that the journal can grow to its fullest degree of usefulness only through the hearty coöperation of the *men who know*.

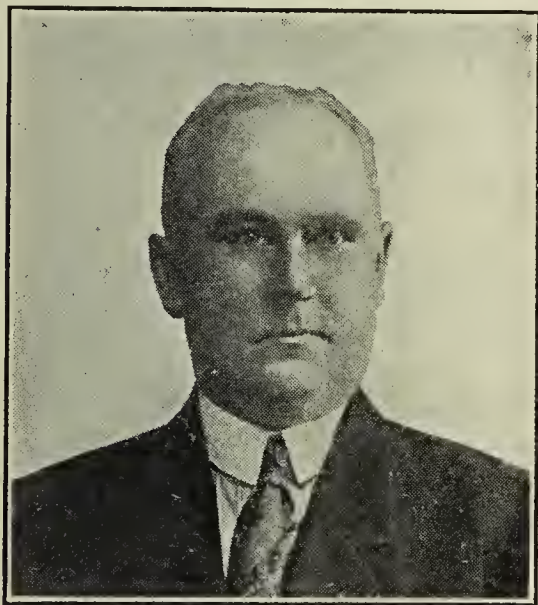
Grateful acknowledgment is made of the splendid assistance rendered by many of the leading technical men of the glass industry. The continuance of such support from manufacturers, technical experts and practical workers alike is required to make *The Glass Industry* what it aims to be, an agency of progress in the field of glass manufacturing.

HISTORY OF THE "NATIONAL GLASS BUDGET"

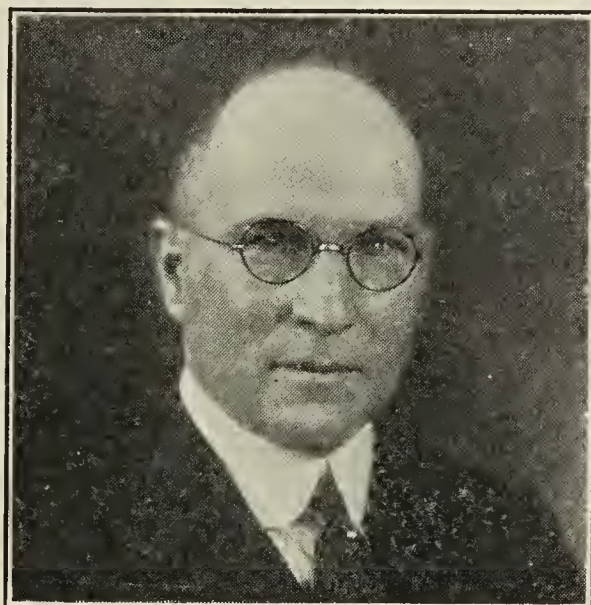
BY A. W. KIMES

The National Glass Budget was established in 1884 by Michael J. Owens and a number of other associates and was then known as the "Ohio Valley Boycotter." The publication retained this name but a short time, changing to the present title at the time of its removal to Pittsburgh in the late '80s, where it has been published continuously thereafter. Soon after coming to Pittsburgh the *Budget* was published by Timothy O'Leary. In 1887, George B. Kimes became associated with the paper and later acquired complete ownership. Under his guidance it became internationally known in the glass industry as a most dependable and fearless exponent of fair dealing between employer and employee, and in the discussion of issues vital to the life and welfare of the glass trade. For

more than a decade Frank M. Gessner was editor of the *Budget* and his fearless editorial remarks, always presented with the best interest of the industry in mind, were severely criticized by those advocating selfish principles. After Mr. Gessner's death, which occurred in 1906, George



GEORGE B. KIMES



ARTHUR W. KIMES

B. Kimes assumed the editorship as well as management, in which capacities he continued until the time of his death on May 30, 1919. He was prominently known in all branches of the glass industry and it can truthfully and justifiably be said of him, as well as Mr. Gessner, that in their respective positions they had no close competitors. Since 1909, Arthur W. Kimes had been associated with his brother George and upon the latter's demise became managing editor, with Thomas A. Kimes as secretary. These two latter gentlemen are the present owners and publishers. For more than 27 years prior to 1922, George J. Eibel, Jr., was associated with the *Budget* in various capacities.

The National Glass Budget was severely censured and criticized during the '90s for advocating the introduction of mechanical means in the art of glassmaking but, hewing true to the line, it stood firmly for what it then believed and since has proven to be correct, that the glass industry in order to keep pace with other lines of trade would necessarily be compelled to progress from manual to machine methods of manufacture. Holding fast to this belief, the *Budget* is now published on the same principle, advocating those policies that are best for all those interested in the manufacture and distribution of all kinds of glass and glassware.

To the *Budget* belongs the credit for having first written up practically every new innovation in the way of glass manufacturing machinery and predictions made have become a reality.

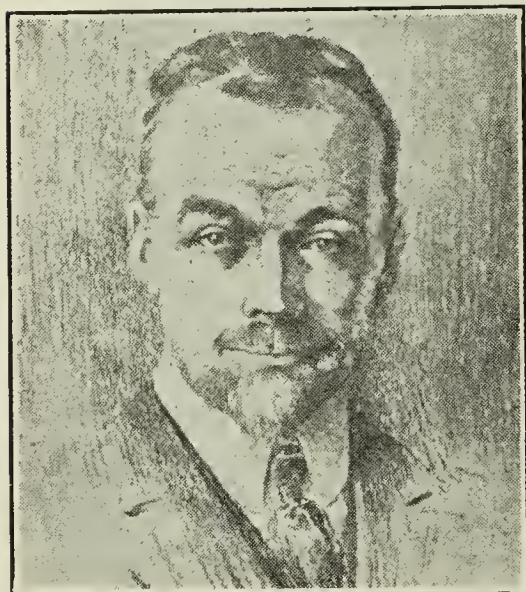
A SHORT HISTORY OF "ROCK PRODUCTS"

BY C. F. DARLING

Rock Products was founded in Louisville, Kentucky, in 1902, by E. H. Defebaugh. This was the same year that the Portland Cement Association was founded, and each of the two organizations recently celebrated their twentieth anniversaries. In the year following, 1903, Mr. Defebaugh called together the first meeting of lime producers, which resulted ultimately in the formation of the National Lime Association, now a large and prosperous association.

Up to 1902 the field covered by *Rock Products* had been practically unrecognized, and while it was even then large and important as a basic industry, the growth of the past twenty years has been remarkable.

Rock Products was founded with an objective that has always been consistently maintained—"The mission of *Rock Products* is to serve the trade in any and every honorable way possible, to promote better profits and make life more pleasant for those engaged in the business to which it caters."



NATHAN C. ROCKWOOD

With the first editor and publisher, Mr. Defebaugh, became associated some time later, Fred Irvine as editor, and the two became well known in the industry. In 1907, the publication offices were moved to Chicago, where they have been ever since. In 1917, the property was sold by the original owners to the Tradepress Publishing Corporation, and in December, 1917, Nathan C. Rockwood, formerly an editor of the *Engineering News*, became editor of the

magazine. In the past five years Mr. Rockwood has made the industry the object of his special study, and has devoted his whole-hearted efforts to the improvement of the paper. He has given the paper a definite editorial policy and has built it up until it is recognized as the authoritative journal of the gravel, stone, slate and other allied industries, as well as of the cement, lime and gypsum industries.

Rock Products treats particularly of the production and manufacture of these products, but inasmuch as these are industries in which it is impossible to separate the technical from the business, *Rock Products* has become to this industry what *Iron Age* is to the iron and steel industry, a technical, business and statistical medium and guide.

The character of *Rock Products* was radically changed in 1917 and 1918 when it was taken over by the present owners. Founded originally as

a producer's paper, in the course of ten years it lapsed into an attempt to cover the whole field of both production and distribution. Under Mr. Rockwood's direction, the field of distribution was eliminated in the editorial contents so far as the appeal to dealers only was concerned and the paper has since stood as one edited entirely for the producers and manufacturers of the non-metallic mineral industries.

A BRIEF HISTORY OF "CHEMICAL ABSTRACTS"

BY E. J. CRANE

Chemical Abstracts, a semi-monthly journal published by the American Chemical Society, was started in 1907. It may be considered the outgrowth of a project inaugurated by Arthur A. Noyes in 1895 for the purpose of gathering together abstracts of chemical papers published in this country. The *Review of American Chemical Research* was the name of this earlier publication. It was discontinued when *Chemical Abstracts* was started. William A. Noyes was the first editor of *Chemical Abstracts*; he was at that time also editor of the *Journal of the American Chemical Society*. To him much credit is due for the organization of the work. He was followed in 1908 by Austin M. Patterson who continued as editor until 1914. John J. Miller, who served as associate editor for several years, was editor during a part of 1914. He left this work soon after his appointment as editor and the editor from 1915 up to the present time has been E. J. Crane. Many of America's most prominent chemists have served or are serving as assistant editors or abstractors. About two hundred and fifty abstractors are on the staff of the journal.

Chemical Abstracts is not restricted in the field it covers to chemical papers published in America but makes every effort completely to abstract the current chemical literature of the world, including patents. New books of interest to the chemist are also listed, with references to reviews when reviews can be located. The industrial side of chemistry receives the same attention that is given to theoretical papers. Some notion of the magnitude of the current chemical literature can be obtained by noting the number of abstracts published in a single year in *Chemical Abstracts*. In 1921, 19,476 abstracts were published, 15,211 of which were taken from journal articles and the remainder from patents. These, with the indexes cover 4,949 pages or an average of 206.2 pages per number.

Special attention is given to the indexing, particularly the subject indexing. The annual index number with its separate author, subject and formula indexes, can be used with confidence as a key to the whole of the literature of chemistry for the period covered. A collective index

to the first ten volumes (1907-1916) has been published. It consists of two volumes devoted to authors, 1,980 pages, and two volumes devoted to subjects, 2,843 pages.

An effort is made to have each abstract prepared by a chemist who is a specialist in the particular field involved. Quality of abstracts is further safe-guarded by the editorial supervision of men of high standing in their branches of chemistry who serve as Assistant Editors, one or more being in charge of each of the thirty sections into which the abstracts are classified.

While most of the abstracts are prepared in this country a few are obtained by coöperative arrangement with the two British chemical societies, namely, The Chemical Society and the Society of Chemical Industry. A coöperative arrangement with the *Journal of the American Ceramic Society* is also in effect, working to the advantage of both journals.

OHIO STATE UNIVERSITY
COLUMBUS, OHIO

"JOURNAL OF INDUSTRIAL AND ENGINEERING CHEMISTRY"

The *Journal of Industrial and Engineering Chemistry*, as its name implies, covers the broad field of the application of chemical science. In its columns are found contributions from the laboratories of practically every university and industrial research organization in America. This material covers a wide range of subjects, for example, dyes and textiles, the metals, leather, cellulose, rubber, fertilizer, petroleum, agriculture and food, medicinal products, sanitation, etc. Some papers are written from the engineering point of view; others point out the industrial application of discoveries in pure science; while a third group deals with analytical processes or new laboratory apparatus. From time to time features appear such as statistical surveys of the chemical industries of other countries, articles from such laboratories as that of the Chemical Warfare Service, or articles and bibliographies by writers, expert in the subjects treated. Monthly letters from correspondents in Washington, London and Paris are included. Each issue covers reports of meetings of scientific bodies, general news items, notes from the industrial field, changes in business connections, personal notes, etc. Government publications in the technical field, reviews of new books, a list of recent journal articles, and chemical market conditions are summarized. A special feature of the *Journal of Industrial and Engineering Chemistry* is the editorial pages.

This *Journal* has taken first rank as an advertising medium in the industrial and engineering chemistry fields and is edited by H. E. Howe.

"THE JOURNAL OF THE AMERICAN CHEMICAL SOCIETY"

The *Journal of the American Chemical Society* is now in its forty-third year of continuous publication. Starting with yearly volumes of only a few hundred pages, it has increased until recent volumes contain nearly 3,000 pages; and this in spite of the relief afforded by the establishment of *Chemical Abstracts* in 1907, and of the *Journal of Industrial and Engineering Chemistry* in 1909. With it was incorporated, in 1914, the *American Chemical Journal*.

Today, most of the contributions to pure chemistry made and published in America, appear in its pages. Many foreign chemists, too, in increasing numbers find it advantageous to publish accounts of their investigations in this *Journal*. In addition to these records of research, the *Journal* contains the Proceedings of the Society, and numerous reviews of books on pure chemistry and related subjects. No scientific library and no person interested in the progress of theoretical, physical, inorganic, organic, pharmacological, or biological chemistry can afford to be without it.

The *Journal* published monthly in numbers of about 250 pages each, is edited by Arthur B. Lamb and an efficient staff of associate editors.

RESEARCH LABORATORIES

OUR FEDERAL, STATE, SEMI-PUBLIC INSTITUTES AND INDUSTRIAL LABORATORIES

The Federal Bureaus.—From the beginning, this SOCIETY has advocated and in every legitimate manner worked for the establishment of ceramic divisions in the Federal bureaus. Records show that this SOCIETY initiated the first organized efforts to obtain the necessary enactments and appropriations.

The benefits to the ceramic industries from coöperative relations with the federal bureaus in scientific research is rapidly becoming universally acknowledged. The federal bureaus differ in character from the collegiate departments, but their academic contributions in trained men and in fundamental knowledge have been of no less value.

The Semi-public Institutes.—The Geophysical Laboratory of the Carnegie Institute in Washington, D. C., and the Mellon Institute in Pittsburgh enjoy world-wide renown for their contributions to science—the Geophysical Laboratory because of original work and fundamental scientific observations in fused magmas; and the Mellon Institute for the development of and results obtained from the industrial fellowship method of coöperation in research.

The Research Council.—The very brief and wholly inadequate account of the National Research Council here given recites the purpose and some of the achievements of that organization. It is of especial importance, we believe, to stress the fact that the Research Council was a creation of the industrial leaders in this country because of the need felt for coördination of the several industrial enterprises and the several research agencies. It is significant that the most successful and progressive manufacturing concerns not only maintain extensive research organizations of their own, but have recognized the importance of giving liberal support to universities, federal and state research organizations, and have recognized the importance of coördinating the efforts of the several scientific, technical and trade associations in research.

The Chamber of Commerce of U. S. A.—Through this national organization, the tradesmen and the manufacturers nationally are being prompted to coördinated efforts on problems of safety, elimination of waste, etc., but no service rendered by this Chamber has a greater value than its promotion of technical investigation and pure science research by Trade Associations.

CERAMIC INVESTIGATIONS CONDUCTED BY THE STATES AND THE FEDERAL GOVERNMENT

By A. V. BLEININGER

The States

The earliest interest in the systematic study of the ceramic raw materials and processes was shown by the geological surveys of a number of states, and the first more elaborate report was that on the clays of New Jersey, by Dr. Cook, in 1878, published by the Geological Survey of New Jersey. In this contribution the chemical composition of the clays was given much consideration and the physical structure of the clay particles was discussed very ably. Following the appearance of this report comparatively little was done for some time with the exception of an occasional paper here and there and a number of contributions to the Institute of Mining Engineers. But in the beginning of the nineties a revival of interest in clays occurred, which was marked by the reports of H. Ries on the quaternary clay deposits of the Hudson river valley, N. Y. Geol. Rept. No. 10, 1891; of Edward Orton, Sr., on the clays of Ohio and Edward Orton, Jr., on the clay working industries of Ohio, 1893. The last named report was the first to give a connected story of the industrial processes and the principles involved as understood at that time. From this time on in rapid succession many reports on clays appeared, published by as many states, most of which were written by Dr. Ries. Thus we have publications from the states of New York (1892 and 1902), Missouri (1896), Mississippi (1896), North Carolina (1897), Pennsylvania (1898), Indiana (1897 and 1904), Georgia (1898, 1907 and 1908), Louisiana (1899), Kansas (1898), Florida (1900), Alabama (1900), Michigan (1900), Wisconsin (1901) Maryland (1902), Iowa (1904), New Jersey (1904), Kentucky (1905), West Virginia (1906), Virginia (1906), North Dakota (1906), Illinois (1907), Oklahoma and Minnesota. A number of these reports, particularly that of H. A. Wheeler for Missouri, those of Ries for New Jersey and Maryland, of Beyer and Williams for Iowa, of Buckley and Peppel for Wisconsin, of Grout for West Virginia and of Purdy for Illinois, contain original contributions dealing with the technology of clays, of considerable and permanent value.

A bibliography of the official literature on the geology of clays would be very extensive. Most of the reports are restricted to the geological classification and description of the deposits although many of them contain brief summaries of the chemical composition and the physical properties of clays as well as descriptive matter relating to the ceramic industries of the state. One geological survey, that of Ohio, under the directorship of Edward Orton, Jr., departed widely from this custom and published reports which are complete treatises on specific industries. This is true of

the bulletins on the manufacture of lime and sand-lime brick by Peppel, on the use of concrete by Eno, on the manufacture of hydraulic cements by Bleininger and on the manufacture of roofing tile by Worcester. The Ohio Geological Survey is still following this policy in part as is also the Geological Survey of Illinois. The latter, for instance, in its volume on the paving brick materials of the state, by Purdy, presents the results of extensive laboratory investigations.

The quality of the many state reports differed quite widely and in some of them both the methods of testing and the results obtained were subject to criticism. Frequently the work was fragmentary and the conclusions drawn were of no practical value to the industries. This lack of unity and correlation in the ceramic work of the state surveys created the feeling that there was needed a federal institution which could do fundamental work in the study of the properties of ceramic materials, in the formulation of testing methods and in the interpretation of the results obtained. Such investigations would be entirely too costly to be undertaken by any single state survey. The AMERICAN CERAMIC SOCIETY was the first to see the need of this and its secretary, Prof. Edward Orton, Jr., did a large amount of work in bringing about the realization of the plan. He not only appealed to the officials of the U. S. Geological Survey and to Congress as early as 1899, but took active steps to secure the coöperation of the different state surveys. He also called a conference for the discussion of the technical work needed to be done which met in Columbus in 1907. The result of this activity was the establishment of a ceramic laboratory within the Technologic Branch of the U. S. Geological Survey in 1908.

The U. S. Geological Survey

This remarkable Federal organization has for many years contributed geological reports dealing with the sources of ceramic materials, many of them from the pen of Dr. Ries. It had also been collecting statistics of all the mineral industries, including a well-organized section devoted to ceramics under the direction of Jefferson Middleton. It realized the need of specific investigations outside of the strictly geological field which would deal with the technology of the key industries, making use of the rocks and minerals of the country. This need was emphasized particularly by Dr. Joseph A. Holmes who devoted all of his energies to the establishment of federal laboratories devoted to such work. In 1904, we find a congressional appropriation for the analyzing and testing of coal for which purpose a laboratory was established at the Louisiana Purchase Exposition in St. Louis. In 1905, an appropriation of \$227,000, covering the study of all fuels and another appropriation for the study of structural materials, was made. A laboratory for the testing and the study of cement and concrete

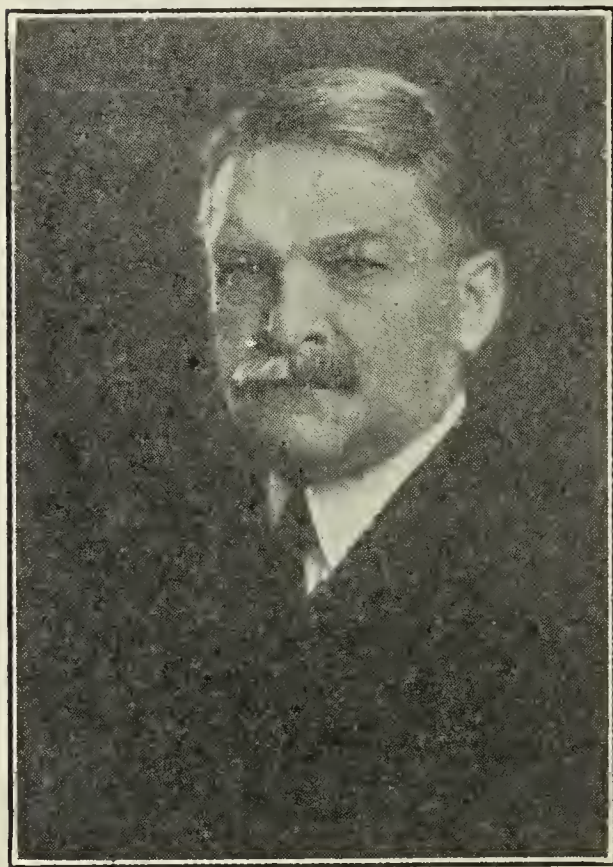
was likewise equipped at St. Louis, under the direction of Richard L. Humphrey. The first chemist to enter this work was P. H. Bates. The fuel work was conducted at St. Louis until 1907 and the structural materials investigations until 1909. In 1907, the Technologic Branch of the U. S. Geological Survey was created, with Dr. Holmes as Chief Technologist. In 1908 the Pittsburgh station was established on the grounds of the Allegheny Arsenal, 40th and Butler Sts. At this time part of one of the buildings was reserved for ceramic work and a clay products section established in charge of A. V. Bleininger. With him were associated H. E. Ashley and, in 1909, G. H. Brown. A kiln house was erected and the equipment gradually increased as the activities of the laboratory expanded. The work consisted in the testing of materials from the public domain and for different government departments, and research. The first investigational work undertaken dealt with the work of Ashley on the colloidal matter in clays, the effect of preliminary heating on clays and the standardization of the load test for refractories. Much work was also done on the mechanical strength of clay products. Of special interest was the study of the colloid phenomena of clays in which Ashley considered deflocculation and coagulation to be the results of direct chemical reactions between chemical compounds and the finely dispersed portion of the clays, a viewpoint recently advocated by Loeb. In 1909, the structural laboratory was removed from St. Louis to Pittsburgh and with it the work on concrete and cement testing. It was at this time that Bates did his work on the effect of soluble salts on concrete. Investigations were also undertaken on the properties of lime and the problems of the lime industry with the assistance of W. E. Emley who later became chief of a section devoted to the study of lime and gypsum products.

The rapid growth of the Technologic Branch and the need of a separate Bureau devoted to the interests of the mining industries resulted in 1910 in the creation of the Bureau of Mines with Dr. J. A. Holmes as its first director. By the same act of Congress the investigational work on structural materials was transferred to the Bureau of Standards. Under this Bureau the researches on ceramic subjects proceeded without interruption.

The Bureau of Standards

This Bureau at once undertook the erection of the ten million pound testing machine provided for by the Technologic Branch which made it possible to conduct tests on a large scale and with which there were made later important tests on concrete columns and brick piers. Before the transfer, the Bureau of Standards had done investigational work on bricks and refractories which was continued. At this time Bates began his studies on the fundamental properties of Portland cement and their correlation

with its microstructure, with the assistance of A. A. Klein, the petrographer of the station. All of the ceramic activities were expanded as more funds became available. The death of H. E. Ashley in 1911, however,



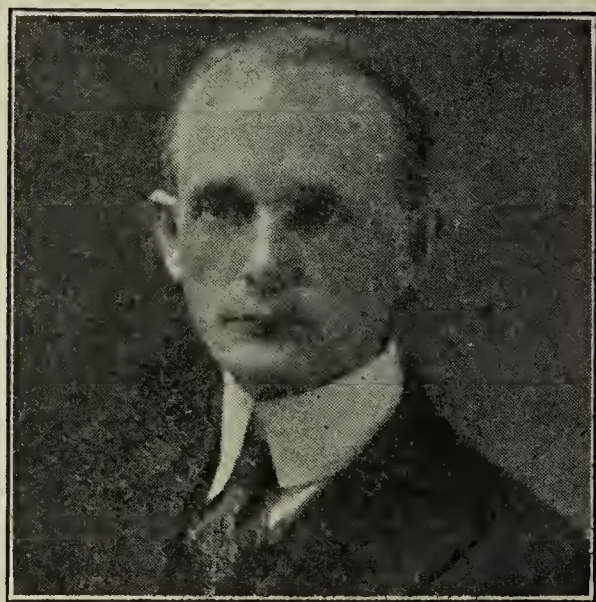
DR. S. W. STRATTON

he reproduction of the Marquardt porcelain body for pyrometer tubes. Brown was first to make tubes of this kind from American materials. He also was chiefly instrumental in preparing the pottery exhibit of the Bureau for the San Francisco Exposition which was awarded a gold medal. In this he was assisted by W. W. McDanel who was in immediate charge of the pottery laboratory. It should be mentioned perhaps that Brown installed the use of the Keppeler caustic soda process for the purification of kaolin in a plant near Saylorsburg, Pa., in 1914.

Bleining, with Kinnison, worked on the study of the Schwerin electrical process for the purification of kaolin, with Teetor on the viscosity of porcelains, with Brown on the mechanical strength of burned clay, with Hornung on the casting of clay slips, etc. A. A. Klein

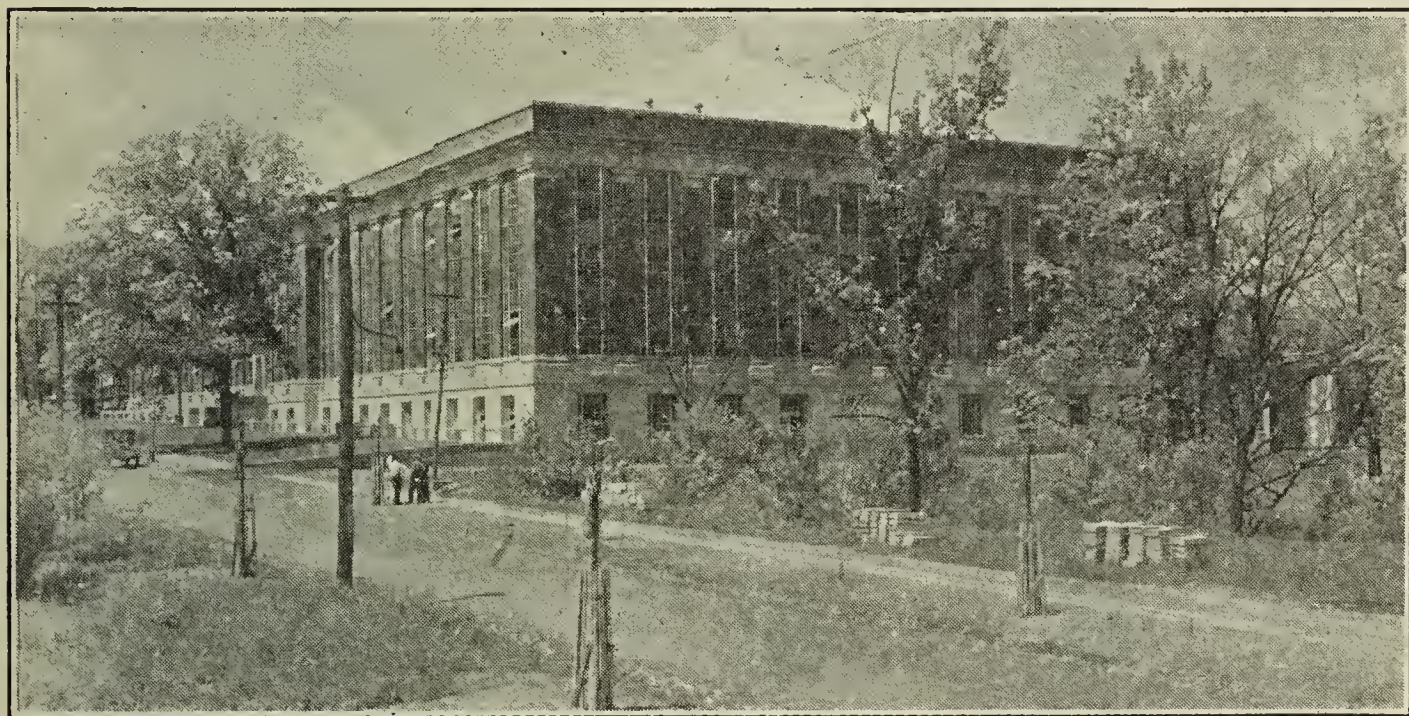
contributed an important paper on the microstructure of porcelain, E. T. Montgomery one on leadless glazes for vitreous ware, W. L. Howat

caused all colloidal research to be abandoned, with the exception of several practical applications which he had pointed out in his work. Emley continued the investigation of lime, its properties, the technology of the lime industry and of sand-lime brick, publishing a number of bulletins and papers on these subjects. G. H. Brown undertook the study of the properties of paving brick in relation to their life in the street, tests of the toughness of clays, the dehydration of clays, the function of time in the vitrification of clays, the effect of mixtures of clay on vitrification, the resistance of refractories to pressure, their resistance to slagging action, the production of synthetic slag bricks, the properties of porcelain bodies and

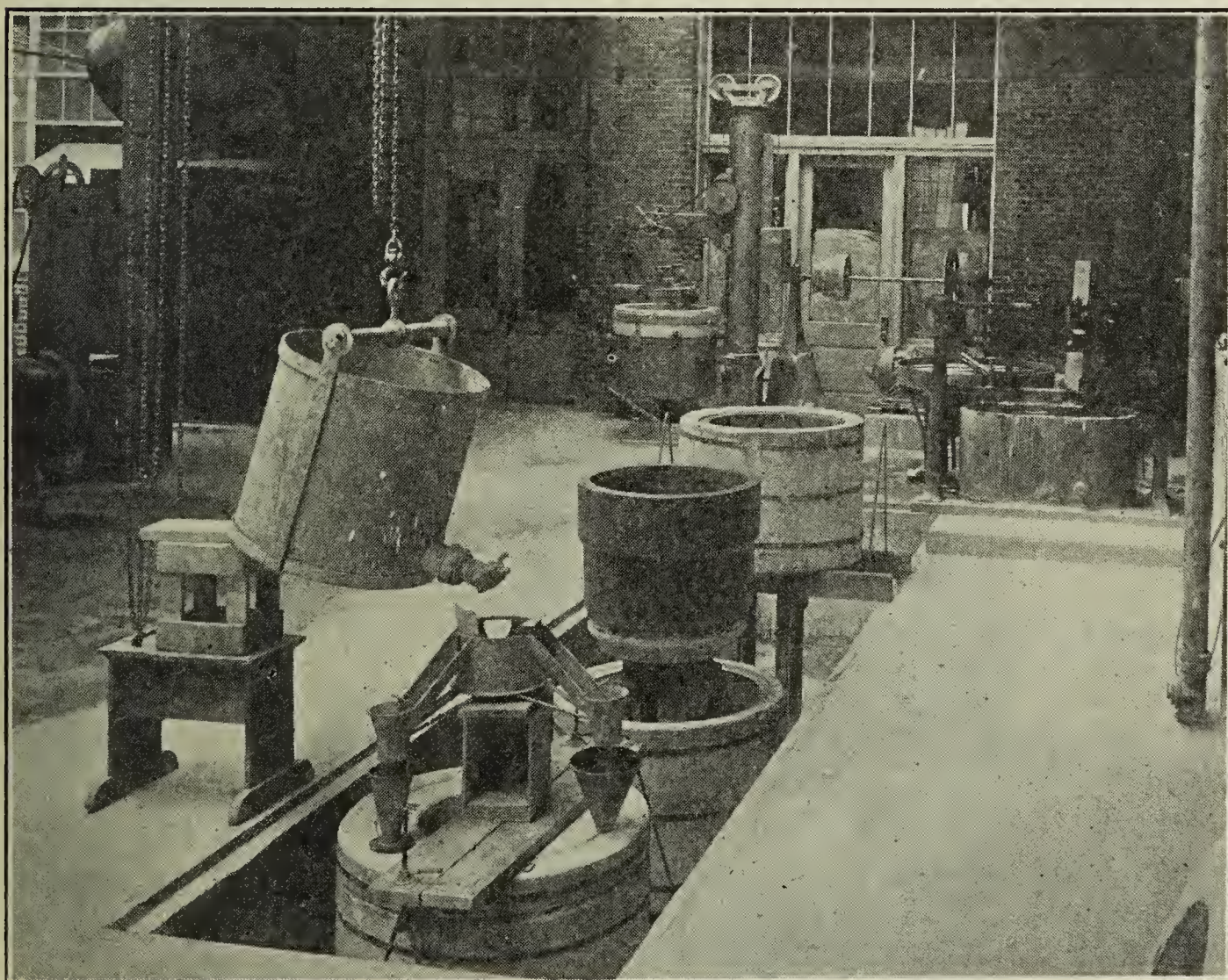


DR. H. FOSTER BAIN, Director U. S. Bureau of Mines.

applied the use of sodium sulphate in an artificial freezing test and again Montgomery worked on the composition of bodies, resisting thermal shock, D. W. Ross undertook at this time the study of silica refrac-



Industrial Building, containing ceramic laboratories, Washington, D. C.

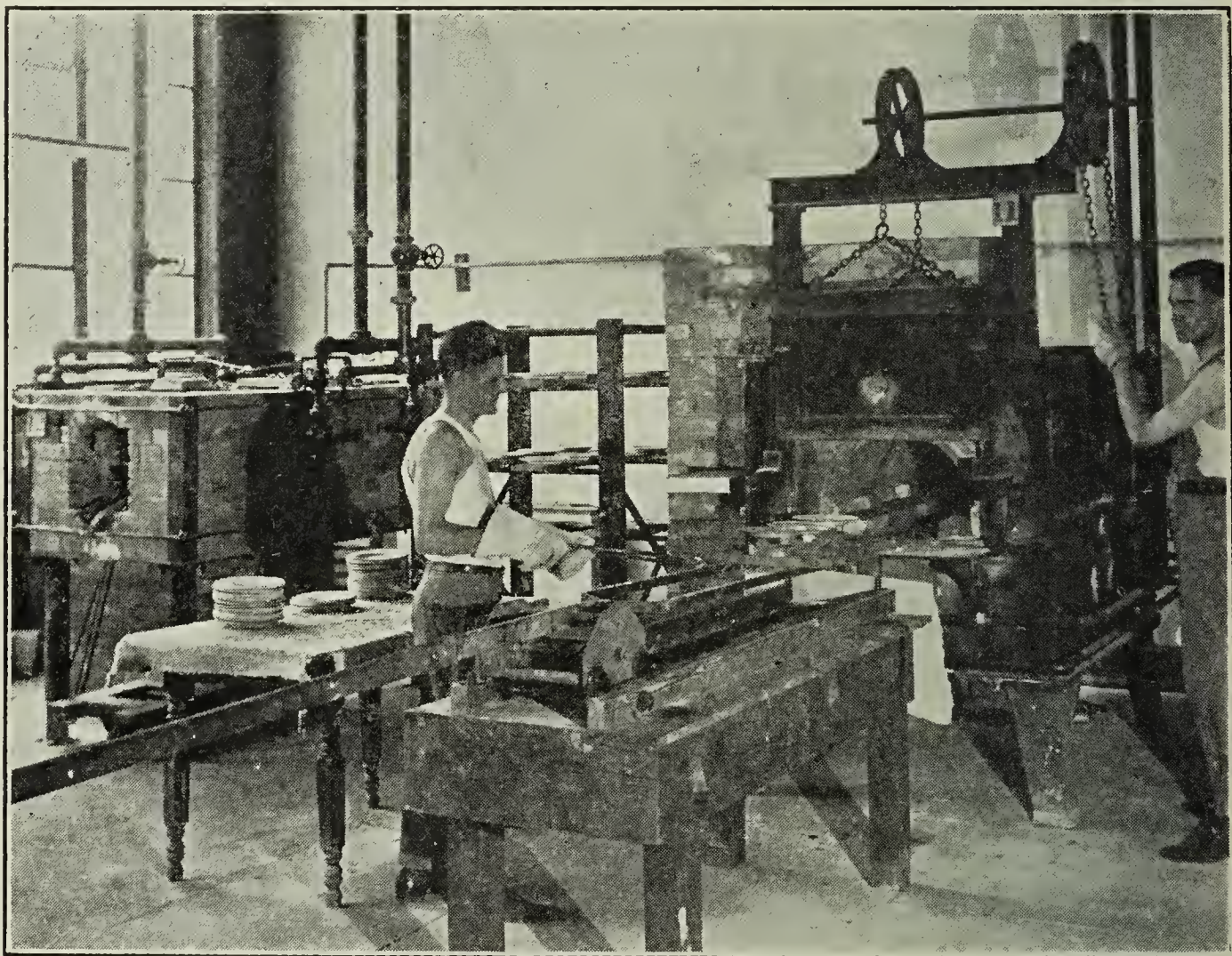


Glass pot casting shop, Bureau of Standards.

tories from the ceramic and Peck, Insley and Klein from the petrographic standpoint.

The fire resistance laboratory established at Pittsburgh, under the direction of W. A. Hull, contributed a number of studies of ceramic interest, particularly in reference to the flow of heat in large size test structures.

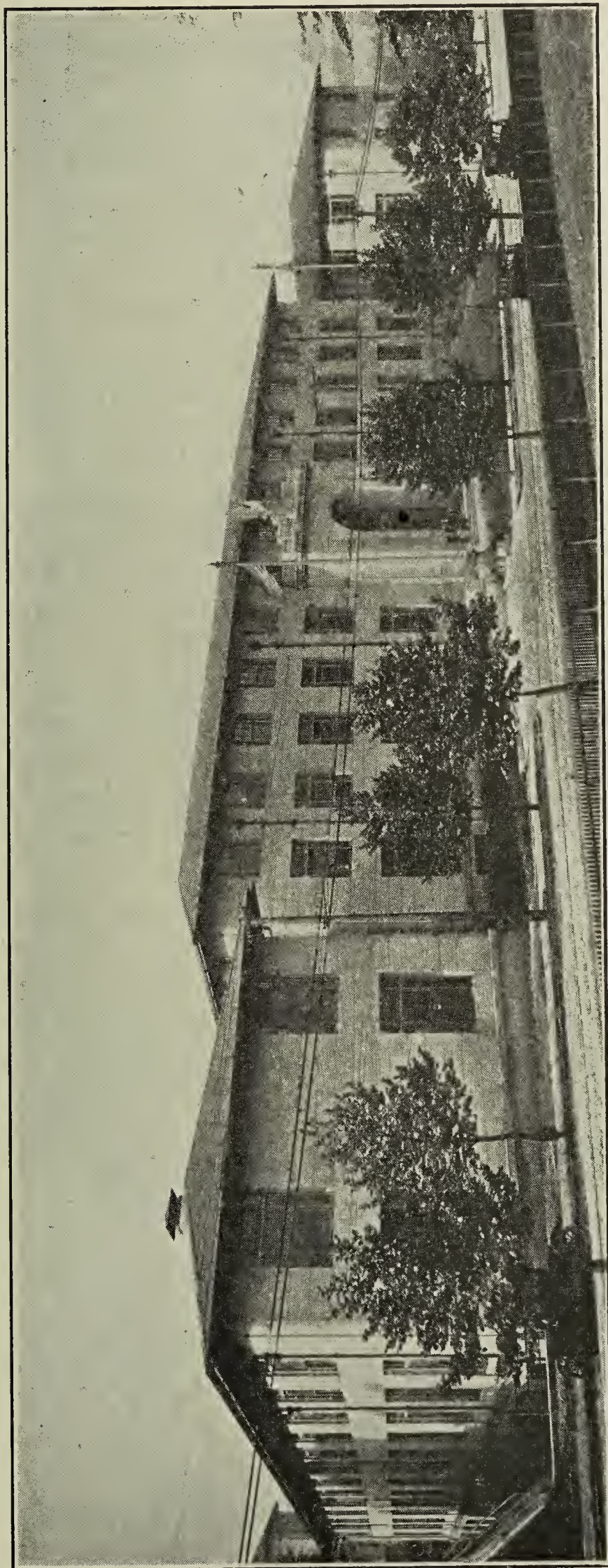
In 1914, the study of the melting of optical glass was undertaken on a laboratory scale, in charge of C. C. Rand and later of A. E. Williams. Work was also begun on the investigation of European bond clays (Bleininger and Schurecht), on the properties of the American bond clays (Bleininger



Enameling laboratory, Bureau of Standards.

ger and Loomis) and the heat behavior of American fire brick (Loomis). At a later date F. H. Riddle, who had taken the place left vacant through the resignation of Prof. Brown, began his extensive investigation of porcelain, both from the laboratory and the factory standpoint.

During the War the work on optical glass was expanded and two glass plants built, one in Pittsburgh and another in Washington, with A. E. Williams in charge. A number of other problems, such as the production of special spark plug porcelains (by Bleininger and Riddle), the production of pyrometer tubes, the pressing and casting of porcelain glass pots, light weight refractories for marine use, the molding of optical glass (Capt. Fry),



Division of Fuels, U. S. Bureau of Mines, Pittsburgh, Pa.

the testing of optical glass (Taylor and Payne), the properties of commercial porcelains (Wright and Sewell), the use of American clays in the manufacture of whiteware (Bleininger and McDanel), etc. were undertaken.

During the war period H. F. Staley became associated with the Bureau as metallurgical ceramist and as ceramic adviser with the War Industries Board. Later he was appointed chief of the refractories and enameled metals sections. In addition to his other work Riddle served as district chief of the Fuel Administration, Furnace Section.

A special appropriation made it possible to erect in Washington a large building for industrial research which contains ample provision for the work on clay products, glass, lime, gypsum, enameled metals and cement. The floor space devoted to ceramics has an area of 43,800 sq. ft. It is probably the largest structure of its kind in the world. From the last of the year 1919, to May, 1920, the ceramic work was removed from Pittsburgh to Washington, where it is now permanently located. In the new building the various activities are being carried on under much more favorable conditions than at Pittsburgh. The glass section particularly possesses exceptional facilities.

Ceramic investigation is making steady progress at this Institution. The work by Danielson on enameled metals has been important as has been that of Bates on magnesia cements, of Hull and Geller on refractories, Sortwell on porcelain glazes, Geller on water-smoking and dehydration, etc.

A system of fellowships has also been established in coöperation with a number of industries. The fellowships now operating are supported by the following organizations: The National Terra Cotta Society, the Hollow Building Tile Association, the four Heavy Clay Products Associations, the Glass Containers Association, the Associated Tile Manufacturers and the U. S. Potters' Association.

The ceramic work of the Bureau of Standards is under the general direction of P. H. Bates and under the direct charge of W. A. Hull, chief of the clay products and glass sections. R. R. Danielson is chief of the enameled metals section and A. E. Williams is in charge of the work on industrial glass.

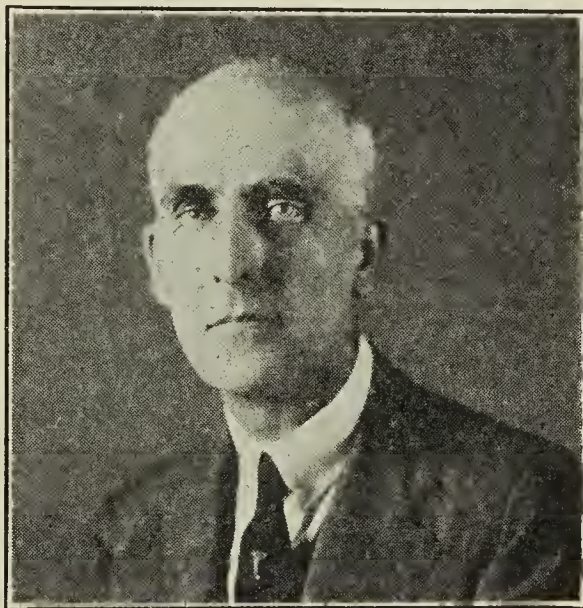
The Bureau of Mines

This Bureau was established by act of Congress, effective July first, 1910. In its creation the membership of the AMERICAN CERAMIC SOCIETY took an active part, especially through the efforts of Prof. Edward Orton, Jr.

The new Bureau began its ceramic work by the appointment of Prof. A. S. Watts who took charge of the field work on the resources and the mining of the kaolins and feldspars of the southern Appalachian region, in 1911. This work resulted in the publication of a comprehensive and valuable report on the subject, known as Bulletin No. 53. The laboratory work

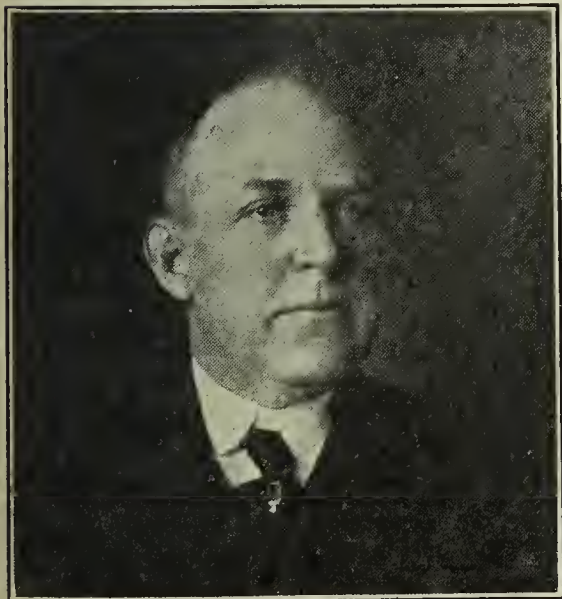
necessary in this investigation was started by Watts at the Ohio State University with a small force. In 1911-12 some work was done also in the ceramic department of the University of Illinois by Robert Back, who later was transferred to the Washington laboratory of the Bureau. This study dealt principally with the effect of electrolytes on clays, the results of which were published in the *Transactions*. Back also began the study of the Keppeler process of purifying clays by the use of caustic soda.

In 1913, H. G. Schurecht joined the staff at the Columbus laboratory where he worked for some years, first under the direction of Watts and later of R. T. Stull. Schurecht contributed a large number of papers on ceramic subjects among which may be mentioned his work on the effect of electrolytes upon clays, the designing of very useful voluminometers, the design of a machine for the determination of the crushing strength of heated fire brick, elutriation tests of Amer-



DR. R. B. MOORE, chief of Division of Mineral Technology, U. S. Bureau of Mines.

ican kaolins, the effect of wet grinding and screening feebly plastic clays, the burning of dolomite, dolomite cements, the separation of the lime from the magnesia in fired dolomites, the microscopic examination of American kaolins, the effect of the firing temperature on the strength of clays and ceramic bodies, the properties of some Ohio and Pennsylvania fire clays, decorative lusters for pottery, aventurine glazes, etc.



DR. D. A. LYON, chief Metallurgist, U. S. Bureau of Mines.

Ira E. Sproat was detailed by the Bureau to study the purification of kaolins by means of caustic soda and utilized the process on a large scale at a Georgia mine. The results of this work appeared as a Bureau publication. Another very practical contribution was that of T. G. McDougal which dealt with the plant aspect of the casting process. Both of these studies were conducted under the supervision of Watts.

In 1917 the ceramic station of the Bureau of Mines at the Ohio State University was established with R. T. Stull as the superintendent. Under his direction the equipment was greatly enlarged and the staff increased. During the War the Bureau was called upon to study

the graphite crucible situation relating to the use of American clays and graphites. This question was of great importance in connection with the production of munitions. A very elaborate and complete investigation was be-

gun which after a great deal of painstaking work showed conclusively that American materials could be used successfully.

A number of papers dealing with subjects relating to this problem have come from the Bureau, dealing with the fusibility of graphite ash, the fusibility of mixtures of clay and graphite ash, the properties of crucible clays, the briquetting of Alabama graphite by means of tar, and the behavior of crucibles made from Ceylon, Canadian and Alabama graphite, tested out under actual operating conditions.

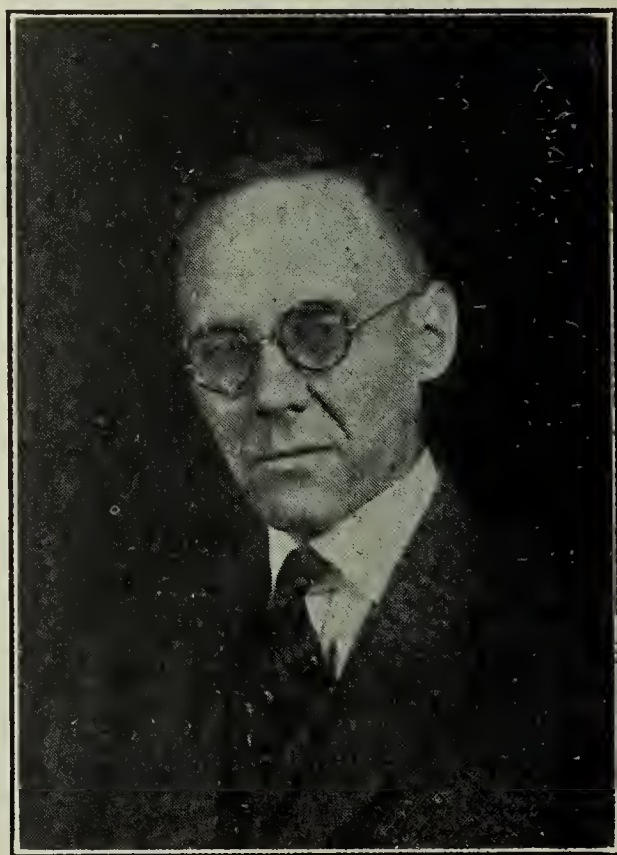
As part of the national program on war minerals the Bureau also undertook the study of American white burning clays

JOHN BLIZARD, Fuel Engineer, U. S. Bureau of Mines, Pittsburgh, Pa.

which might be suitable for the manufacture of pottery, a most comprehensive undertaking. In this connection Stull invented a new type of washing process which he demonstrated on a semi-commercial scale. Additional contributions not already mentioned are those on the dead burning of dolomite and magnesite (Schurecht), on the properties of bentonite (Schurecht and Douda), the properties of refractory clays from California, the mechanical movement of water through clays and



A. C. FIELDNER, Supt., Pittsburgh Station.



G. A. BOLE, Supt., Ceramic Experiment Station U. S. Bureau of Mines

its control, the purification and analysis of zirconium oxide (Jackson), plasticity from the colloidal standpoint (Bole), and the design of an improved porosimeter (Bole).

In 1921, the Bureau of Mines, in coöperation with the Hollow Building Tile Association, the Common Brick Manufacturers' Association, the American Face Brick Association and the National Paving Brick Manufacturers' Association undertook an elaborate and comprehensive study of



Ceramic experiment station personnel, U. S. Bureau of Mines.

Standing left to right: R. C. Zehm, F. G. Jackson, E. P. Ogden, G. A. Bole, R. T. Stull, H. M. Kraner, P. S. Bachman, A. H. Fessler.

Sitting left to right: J. T. Robson, L. E. Geyer, Hazel I. Gibbon, R. T. Watkins, A. V. Henry, R. B. Gilmore.

the burning of the heavy clay products. In this investigation the Bureau also coöperates with the Bureau of Standards which carries on certain laboratory work. Part of the study dealing with the fundamental question of heat absorption has been assigned by the Bureau to E. W. Washburn. The field work, consisting in the study of the actual firing processes in various types of plants, is being conducted jointly by the Columbus station and the Fuels Division of the Bureau. Nearly 30 plants have been studied from this standpoint and the possible fuel economies have been actually demonstrated. This unique work has been greatly assisted by the use of a laboratory railroad car, operated by the Bureau, which is fully equipped and is used to take a staff of six men and their apparatus from place to place. This work which has been done under the close supervision of Stull, when completed, will undoubtedly yield a complete survey of the present

burning processes and definite recommendations towards the reduction of fuel losses.

The Bureau has established also a ceramic station in coöperation with the University of Washington, at Seattle, in charge of Hewitt Wilson, which conducts studies of the raw materials of the Pacific Coast.

In 1922, R. T. Stull was promoted to the position of Supervising Ceramist of the Bureau of Mines and was placed in charge of all ceramic research. G. A. Bole was appointed superintendent of the Columbus station and with him is associated E. P. Ogden as ceramic engineer.

RESEARCH COUNCILS

By E. W. WASHBURN¹

I. The National Research Council of the United States

The National Research Council was first organized in April, 1916, at the request of the President of the United States and during the War it acted as the Department of Science and Research of the Council of National Defense. In May, 1918, the President issued an Executive Order in which he stated that, "The work accomplished by the Council in organizing research and in securing coöperation of military and civilian agencies in the solution of military problems demonstrates its capacities for larger service." The Executive Order further requested that the National Research Council be perpetuated with duties which were set forth as follows:

The National Research Council was organized in 1916 at the request of the President by the National Academy of Sciences, under its Congressional charter, as a measure of national preparedness. The work accomplished by the Council in organizing research and in securing coöperation of military and civilian agencies in the solution of military problems demonstrates its capacity for larger service. The National Academy of Sciences is therefore requested to perpetuate the National Research Council, the duties of which shall be as follows:

1. In general, to stimulate research in the mathematical, physical, and biological sciences, and in the application of these sciences to engineering, agriculture, medicine, and other useful arts, with the object of increasing knowledge, of strengthening the national defense, and of contributing in other ways to the public welfare.

2. To survey the larger possibilities of science, to formulate comprehensive projects of research, and to develop effective means of utilizing the scientific and technical resources of the country for dealing with these projects.

3. To promote coöperation in research, at home and abroad, in order to secure concentration of effort, minimize duplication, and stimulate progress; but in all coöperative undertakings to give encouragement to individual initiative, as fundamentally important to the advancement of science.

¹ Chairman, Division of Chemistry and Chemical Technology, National Research Council.

4. To serve as a means of bringing American and foreign investigators into active coöperation with the scientific and technical services of the War and Navy Departments and with those of the civil branches of the Government.

5. To direct the attention of scientific and technical investigators to the present importance of military and industrial problems in connection with the war, and to aid in the solution of these problems by organizing specific researches.

6. To gather and collate scientific and technical information at home and abroad, in coöperation with governmental and other agencies and to render such information available to duly accredited persons.

Effective prosecution of the Council's work requires the cordial collaboration of the scientific and technical branches of the Government, both military and civil. To this end representatives of the Government, upon the nomination of the National Academy of Sciences, will be designated by the President as members of the Council, as heretofore, and the heads of the departments immediately concerned will continue to coöperate in every way that may be required.

The White House, May 11, 1918.

(Signed) WOODROW WILSON.

In the permanent form given to the Council, it consists of three classes of representatives: first, those of national scientific and technical societies; second, representatives from different branches of the government; and third, representatives from other research organizations. The Council is made up of two general classes or divisions: (a) those divisions concerned with the more general relations and activities of the Council and (b) those concerned with particular branches of science and technology. Under the first class, there are six divisions: namely, Division of Federal Relations, Division of Foreign Relations, Division of States Relations, Division of Educational Relations, Division of Research Extension and Research Information Service. The divisions of science and technology comprise Physical Sciences, Engineering, Chemistry and Chemical Technology, Geology and Geography, Medical Sciences, Biology and Agriculture, and Anthropology and Psychology. More particularly, the purpose of the Council consists in the promotion of research in the mathematical, physical and biological sciences and in the application of these sciences in engineering, agriculture, medicine and other useful arts. In carrying out its work, the Council endeavors particularly to avoid duplicating the efforts of other organizations having similar objects and strives to utilize to the fullest extent existing facilities for research wherever located.

The Council has been entrusted by various foundations, organizations and individuals with the expenditure of large sums contributed in support of special projects and, owing to the nature of its organization and the success which it has had in the past, it seems probable that this branch of its activities will continue and will be materially increased in the future. Among such trust funds may be mentioned two grants of \$500,000 each in support of national research fellowships in chemistry and physics and in medicine.

The AMERICAN CERAMIC SOCIETY is officially connected with the Council through the Division of Chemistry and Chemical Technology to which it nominates one member. Mr. A. V. Bleining has served in this way as the representative of the SOCIETY since the permanent organization of the Council. Early in the history of the Division of Chemistry and Chemical Technology, the Division invited the AMERICAN CERAMIC SOCIETY to join with it in the creation of a Committee on Ceramic Research. This committee was appointed and served until last year when, at the suggestion of the SOCIETY, the committee was discharged since the reorganization of the SOCIETY's activities provided otherwise for the work which had been carried on by the committee.

The Council is at all times ready to assist the scientific societies of the country in furthering and developing any worthy project connected with research. Through its Division of Research Information, it also stands ready at any time to supply individuals with information or sources of information concerning all topics connected with scientific investigation.

Among the publications of the Council the following may be of interest to the members of the SOCIETY:

Report of the committee on ceramic chemistry. Presented for the Com. by E. W. WASHBURN, *chairman*. Washington, April, 1919. Pp. 6. No copies for distribution.

Report of the Com. on Ceramic Research joint committee with the AMERICAN CERAMIC SOCIETY, with reference to a plan for the establishment of a system of research fellowships in ceramics supported by the industries. Submitted by ALBERT V. BLEININGER, *chairman*. November 19, 1919. Pp. 9. No copies for distribution.

Industrial research and national welfare. By GEORGE E. HALE. Reprinted from *Science*, N. S., November 22, 1918, **48**, 505-507. Limited supply distributed free, post. 1 c.

Industrial research and national welfare. By ELIHU ROOT. Reprinted from *Science*, N. S., November 29, 1919, **48**, 532-534. Limited supply distributed free, post. 1 c.

The national value of scientific research. By GEORGE E. HALE. Reprinted from *The Technology Review*, November, 1916, **18**, 801-817. Distributed free, post. 1 c.

The organization of research. By JAMES R. ANGELL. Reprinted from the *Journal of Proceedings and Addresses of the Association of American Universities*, Twenty-first Annual Conference, November 7 and 8, 1919. Pp. 27-41. Distributed free, post. 1 c.

The organization of research in our American democracy. By JAMES R. ANGELL. Preprinted from the *Proceedings of the Institute of Medicine of Chicago*. March 5, 1920. Pp. 18. Distributed free, post. 2 c.

The obligation of the state toward scientific research. By JAMES R. ANGELL. Reprinted from the *Centennial Memorial Volume* of Indiana Univ. July, 1921. Pp. 12. Limited supply distributed free, post. 1 c.

The new opportunity in science. By R. A. MILLIKAN. Published in *Science*, N. S., September 26, 1919, **50**, pp. 285-297. No copies for distribution.

America's place in industrial research. Address given at the decennial celebration, Forest Products Laboratory, Madison, Wisconsin, July 23, 1920, by H. E. Howe. Pp. 18. Limited supply distributed free, post. 2 c.

Research in America after the war. By R. A. MILLIKAN. Reprinted from the *Transactions of the American Institute of Electrical Engineers*, 1919, pp. 129-140. Distributed free, post. 1 c.

The research spirit in everyday life of the average man. By JOHN C. MERRIAM. Reprinted from *Science*, N. S., 52, pp. 473-478, November, 1920. No copies for distribution.

The national importance of scientific and industrial research. By GEORGE ELLERY HALE and others. October, 1919. Pp. 43. Price \$0.50.

Periodical bibliographies and abstracts for the scientific and technological journals of the world. Compiled by R. COBB. June, 1920. Pp. 24. Price \$0.40.

Funds available in 1920 in the United States of America for the encouragement of scientific research. Compiled by CALLIE HULL. March, 1921. Pp. 81. Price \$1.00.

Research laboratories in industrial establishments of the United States, including consulting research laboratories. Originally compiled by ALFRED D. FLINN. Revised and enlarged by RUTH COBB.

Report of the Patent Committee of the National Research Council. Presented for the Committee by L. H. BAEKELAND, Acting Chairman. February, 1919. Pp. 24. Price \$0.30.

Refractory materials as a field for research. By EDWARD W. WASHBURN. January, 1919. Pp. 24. Price \$0.30.

Industrial research. By F. B. JEWETT. 1918. Pp. 16. Price \$0.25.

The development of research in the United States. By JAMES ROWLAND ANGELL. November, 1919. Pp. 13. Price \$0.25.

Science and the industries. By JOHN J. CARTY. February, 1920. Pp. 16. Price \$0.25.

A reading list on scientific and industrial research and the service of the chemist to industry. By CLARENCE JAY WEST. April, 1920. Pp. 45. Price \$0.50.

The relation of pure science to industrial research. By JOHN J. CARTY. October, 1916. Pp. 16. Price \$0.20.

Industrial benefits of research. By CHARLES L. REESE and A. J. WADHAMS. February, 1921. Pp. 14. Price \$0.25.

II. National Research Councils in Other Countries

Following the example of the United States, a number of other countries of the world have set up organizations having purposes more or less similar to those of our National Research Council. Thus, in Great Britain the Department of Scientific and Industrial Research was organized as a branch of the Government with purposes essentially identical with those of our National Research Council. Similar organizations have also been created in the following countries: In Australia, the Commonwealth Advisory Council of Science and Industry; in Canada, the Advisory Council for Scientific and Industrial Research; in New Zealand, the National Advisory Council on Research; in Italy, a National Research Council; and in Japan, a National Research Council. Similar organizations are also under consideration or in process of formation in other countries.

III. The International Research Council

Through the initiative of the National Academy of Sciences of the United States, there has been established an International Research Council.

cil with headquarters at Brussels. This international body is composed of representatives of the research councils, or similar bodies, in the various countries. It is organized upon divisional lines very much as our National Research Council, its divisions being called unions; thus, for example, the division of chemistry is called the International Union of Pure and Applied Chemistry. These divisions have their own officers and are largely autonomous. The International Research Council meets triennially but many of the unions meet at more frequent intervals. Through the work of the unions, a large measure of international coöperation on research on scientific questions having international aspects has been inaugurated and, owing to the frequent meetings of these unions, they serve as a convenient channel for international scientific relations. The delegates to the international meetings of the International Union of Pure and Applied Chemistry are appointed by the National Research Council upon recommendation of its Division of Chemistry and Chemical Technology, and the AMERICAN CERAMIC SOCIETY has the privilege of nominating delegates to these meetings.

SERVICE IN WASHINGTON

What the Chamber of Commerce of the United States of America is Doing for the Industry¹

National Chamber of Commerce

Visitors to Washington, the Nation's Capital, will soon have an opportunity of visiting a new building, which will be numbered among the most beautiful and substantial structures in that city of beautiful buildings. The Chamber of Commerce of the United States is now constructing a national home for organized business, which it is hoped will typify in appearance the dignity and stability of American commerce and industry.

This organization had its birth in a realization of the necessity for American business to have efficient and organized representation at the Nation's Capital to render assistance to the President, the Congress and the various Government Departments on all matters concerning the industrial welfare of the Nation.

Organized in 1912, the National Chamber has for almost 11 years been the guardian of the interests of American business. No piece of legislation, however small or unimportant, which is national in its scope, escapes the attention of the Chamber. It will be readily realized that the

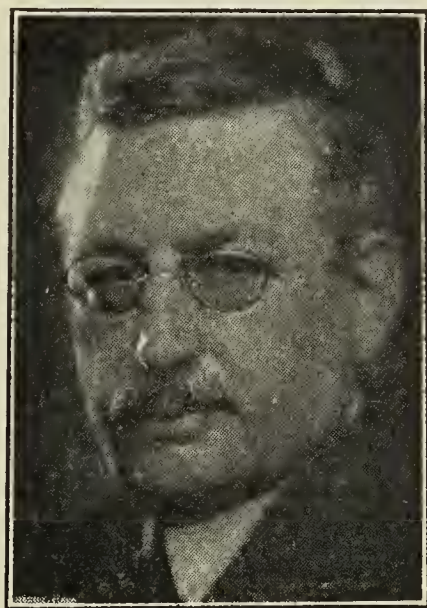
¹ Contributed by the Fabricated Production Department, Chamber of Commerce of the U. S.

members of our national law making body called upon to deal with such a wide variety of problems cannot individually make complete preparation to meet all of these problems. It was to provide an organization capable of supplying the necessary facts and information, free from political or partisan influence and of unbroken continuity, that the Chamber was created.

This organization has grown steadily until it now consists of over 1300 organization members and more than 13,000 associate and individual members, representing an underlying membership of about 767,000 firms and individuals in all the 48 states, our insular possessions and several foreign countries. This growth led to such an increased demand for service that the Directors of the National Chamber, some three years ago, organized its activities by departments to provide a means of rendering real service in solving the problems confronting the various groups of American business men. These departments are headed by managers and supported by staffs who have been trained through practical experience and are experts in their respective lines. They are constantly furnishing in printed form and by letters and telegrams the results of impartial studies of their experts.

These representative departments, cross sections of American business, are: Civic Development, Domestic Distribution, Fabricated Production, Finance, Foreign Commerce, Insurance, Natural Resources, Production and Transportation, and Communication.

Each of these departments serves as a channel through which the problems of their clientèle are investigated and thrashed out, then brought before the Board of Directors of the Chamber for consideration, if desirable. If the problem is national in scope it is brought before the entire membership of the Chamber to secure the opinion and, if that opinion be favorable, the support of all American business to the plans which have thus been analyzed and passed upon. By such departmentalization provision is made for an intensive study of the problems peculiar to each division of business. An intimate relation is established between each department and the interest it is particularly charged to represent so that in technical matters or in functions that overlap, all divisions of industry can be brought together through the same machinery (referendum), for ascertaining the opinion of American business, which has been found so effective and beneficial during the past ten years.



E. W. McCULLOUGH,
manager, Fabricated
Production Department,
Chamber of Commerce of U. S. A.,
Washington, D. C.

The Fabricated Production Department, one of the eight principal divisions of the Chamber, has for its field of service the investigation and solution of the common problems of manufacture. It has been working closely with the various lines of the ceramic industry and has given its support to many constructive undertakings within the industry.

In order that there may be no confusion between the scope of activities of the Fabricated Production Department and the Natural Resources Production Department, in both of which the ceramic industry has an interest, it would be well to clarify the line of demarcation separating the two departments. It is, therefore, considered that after raw materials or natural resources have received their first treatment in fabrication, *i. e.*, when ore is converted into pig iron, logs into lumber, cotton ginned and baled, etc., all problems arising thereafter in their further conversion into merchantable commodities will come within the scope of the Fabricated Production Department. It will be seen from this that insofar as ceramics is concerned practically all of its problems lie within the field of service of this department.

The policy and function of the Fabricated Production Department, determined by the Manager and his Advisory Committee, is to deal with these common problems of manufacture in an educational way, coöperating with its members in the study of their problems and aiding them through information obtained by research and the interchange of experiences. It has no desire nor intention to duplicate the work of government or other bureaus which are now rendering adequate service, but aims to coöperate with them in a manner that will aid in strengthening and upbuilding them. Problems may be brought to the attention of the department by organizations, by associate or individual members direct, or through the organizations of which they are members. In order that the department may have certain definite objectives to develop in its working plans, the following principal activities have been selected for special attention: (1) Cost Accounting, (2) Standardization and Simplification, (3) Business Statistics, (4) General Production Problems of a nature too indefinite to permit of classification.

Cost Accounting

There is no problem confronting manufacturers today of greater or more vital importance than that of the use of proper methods of cost accounting. A former Chairman of the Federal Trade Commission, a few years ago, made the statement that 80 per cent of the manufacturers of the country did not have correct information as to the costs of the products they produced. Whether one agrees with this statement or not, it is clear that no permanent success can be attained in manufacturing without proper attention being given to costs.

To deal with this subject adequately there has been formed within the Fabricated Production Department a very efficient Cost Accounting Bureau in charge of a cost expert. This Bureau has investigated almost every line of industry, both organized and unorganized, and has in its files some 120 systems of Cost Methods which have been adopted by the various lines. A progress chart was recently prepared showing the industries or commodity lines in which uniform cost accounting has been achieved or attempted, and it is interesting to note that the major portion of the progress of cost accounting work in the United States has been in recent years.

The various branches of the ceramic industry have all made use of the services of the department in the cost accounting field, but so far in only two of them, the face brick and the refractories manufacturers, has a definite uniform system been devised and installed. The latter group, the Refractories Manufacturers, has gone further and formed, within their organization, a Cost Accountants Institute where the accountants of their members may meet and discuss the latest developments in the cost accounting field.

The Common Brick Association has asked for and used some of the publications of the department, and it is hoped that in the near future some constructive steps towards a uniform cost system will be taken by that group. In like manner the Paving Brick Manufacturers have used the literature of the department, and in addition have made an appropriation for carrying on the cost work. The Clay Products branch and the Hollow Building Tile branch of the ceramic industry both expect in the near future to go ahead with a program of cost work. The Pottery Association also is giving a place to this work on the program of their annual convention and will doubtless make definite progress along these lines after that meeting.

Extensive study and research on specific phases of cost accounting has been carried on and the results have been made available to manufacturers in the following pamphlets: (1) What a "Cost System" Should Do for You, (2) Overhead Expenses—How to Distribute Them in Good and Bad Times, (3) Depreciation—Its Treatment in Production, (4) Perpetual Inventory or Stores Control, (5) Budgeting for Business Control.

It has also issued special bulletins and reports on other Cost Accounting subjects.

So far only the trade association aspect of Cost Accounting work has been covered but the Cost Bureau is pushing with equal emphasis the formation of Cost Councils within Chambers of Commerce to provide a meeting place where the cost accountants of the various Chamber members may meet and interchange ideas and policies. This effort has been ex-

tremely successful and there are now in existence some 15 such Cost Councils in active operation. In addition there are 25 other cities, spread from coast to coast and from the Gulf to the Great Lakes, which are displaying an active interest in this activity and in which at any time a Cost Council may be formed.

Standardization and Simplification

Intimately connected with cost accounting problems are those relating to standardization, simplification and the elimination of unnecessary variety. The Fabricated Production Department has conducted an investigation of some 350 commodity lines and has been responsible for accomplishments of wide-reaching effects. One of the most notable instances is in the paving brick line. At a conference held at the Department of Commerce, sponsored by the Fabricated Production Department, manufacturers, users and all interested parties discussed the 66 varieties of paving brick then being manufactured, and in a single day agreed on a reduction to 11 varieties. This was carried still further at a later conference and the number reduced to 7. The economies resulting are self-evident to all progressive manufacturers.

Other branches of the ceramic industry with which the department has been working on Standardization, and the present status of the work in those branches, are as follows:

Common Brick.—Common brick have been standardized as to size, there being only one size now produced. This was accomplished before the Fabricated Production Department engaged in Standardization activities.

Face Brick.—Size standardized and is identical with that of common brick. There seems to be little disposition on the part of manufacturers to in any way reduce the apparently wide variety of texture, color and style of face brick.

Sewer Pipe Clay.—The association representing the Eastern Manufacturers have their survey complete and data tabulated and are ready for a conference to adopt standards. The association representing the Middle Western Group, while interested in standardization, have as yet not compiled the information necessary to join in any conference looking towards national standardization.

Sanitary Pottery (Household).—In coöperation with the Bureau of Standards, standardization possibilities are being worked out. During the War, manufacturers of sanitary pottery made a 40% reduction in their varieties which curtailed list, it is understood, is still in operation.

Refractories.—Standardization accomplished by the Association, which has decided upon a fixed number of styles and shapes which they consider standard. All others are considered special orders.

Stoneware.—Through the efforts of the Fabricated Production Department, this branch of the industry has started an investigation in their many lines as to the possibilities for simplification and standardization. Considerable interest has been aroused, but no definite action as yet taken.

Interior Tile.—Standardization accomplished through the Association and varieties reduced from 735 to 115.

Hollow Building Tile.—Now making a survey, on the initiative of the Fabricated Production Department, and upon completion of this survey a simplification conference will be held.

There are probably many other branches of the ceramic industry where this question can be advantageously considered and a great deal of progress made if the parties most interested will get together and coöperate. The service and good offices of the Fabricated Production Department are available for this purpose at all times, to call a conference of all interested parties as in the paving brick case, or by any other means which may seem feasible.

Business Statistics

To determine the unprofitable lines of commodities produced, and for many other constructive uses, adequate business statistics are essential. Much of the trouble in our recent business depression could possibly have been avoided had there been available accurate information as to stocks on hand, quantity being produced, etc., in various commodity lines. False reports and figures led to a runaway market and later, when true facts became known and accumulated stocks were dumped on the market, it broke sharply and widespread business depression followed. The Fabricated Production Department is encouraging all lines of industry to make provision to gather as complete figures as possible on all statistical items vital to the industry.

In a recent survey, in which the department received replies from 246 associations, the returns showed that some 130 of these were now doing statistical work. The principal types of statistics now being gathered are as follows, the figure after each type representing the number of associations engaged in the collection of statistics on that particular subject:

Shipments.....	54	Production.....	47
Stocks on hand	34	Orders—new.....	31
Orders—unfilled.....	30	Sales.....	23
Wages and labor conditions...	19	Orders—cancelled...	11
Cost of doing business.....	10		

Many other types were mentioned, but the limitations of this article will not permit their inclusion.

The advantages of gathering adequate and reliable statistics have been

strongly phrased in the following manner by a leading trade association executive:

GOOD STATISTICS TELL A MANAGER

1. When to buy—when to sell.
2. When to hire—when to fire.
3. When to run—when to shut down.
4. When to distribute earnings—when to conserve cash.
5. When to stock—when to unload.
6. When to mark up—when to mark down.
7. When to borrow—when to pay.
8. When to expand—when to retrench.
9. When to push on—when to hold back.
10. When and how he can earn profits—when and how he must avoid losses.

Innumerable other advantages could also be cited.

Naturally enough the gathering of business statistics leads, to a greater or less degree, to the field of research work. Here again the Fabricated Production Department has been active in conducting a preliminary survey of those industries which are now carrying on this work and making the returns available in the form of a Bulletin to all interested parties. Many of the branches of the ceramic industry are now conducting extensive research work, and it is to be hoped that still others will realize the value of such work and arrange to engage in it in the near future.

General Problems

This article has only touched upon the high spots of the service of the Fabricated Production Department, but there are other production and manufacturing problems, too numerous in range and diversification to attempt to cover them in a brief article.

The department is in charge of Mr. E. W. McCullough, a man of wide experience, thoroughly familiar with manufacturing problems, who is assisted by a staff of experts in their respective lines. It is his desire to render efficient and practical service to manufacturers, and in furtherance of this desire the department keeps in touch with the work of the various divisions and bureaus of the Department of Commerce, Treasury Department, Federal Trade Commission, and other Governmental Agencies, working in the closest coöperation with all of them.

To all members of the ceramic industry, regardless of the branch to which they may belong, the Fabricated Production Department extends an invitation to make the fullest possible use of its service, with the assurance that such requests for assistance will meet with a most cordial response.

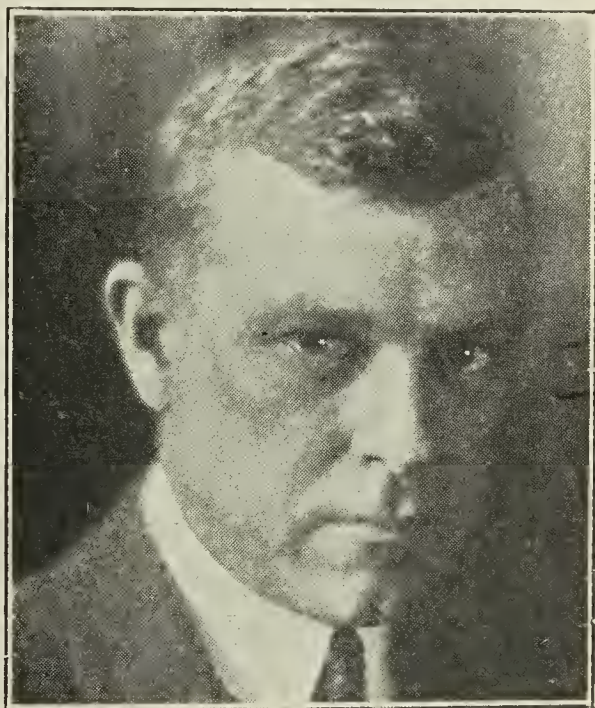
CERAMIC INVESTIGATIONS AT THE MELLON INSTITUTE OF INDUSTRIAL RESEARCH

By EDWARD R. WEIDLEIN¹

The Mellon Institute of Industrial Research is a center for technical investigation in chemistry, chemical engineering, ceramics, and allied subjects. Its purpose is to promote industrial success through scientific research; in other words, to find new materials and new processes for industrial development, and to advance manufacturing through the application of scientific methods to industry. The Institute is a part of the University of Pittsburgh and enjoys close coöperative relationships with all schools of the parent institution.

The working plan of the Institute is based upon the Industrial Fellowship System formulated by Dr. Robert Kennedy Duncan in 1906. This System, which was operated primarily in the University of Kansas, was inaugurated at the University of Pittsburgh in 1911.

In 1913, Messrs. Andrew William Mellon, now Secretary of the Treasury, and Richard Beatty Mellon, a banker of Pittsburgh, established the Mellon Institute of Industrial Research on a permanent basis as a memorial to Judge Thomas Mellon, their father, and to Dr. Duncan. The continued financial support of the Messrs. Mellon has made it possible to develop the Industrial Fellowship System to its present strong position.



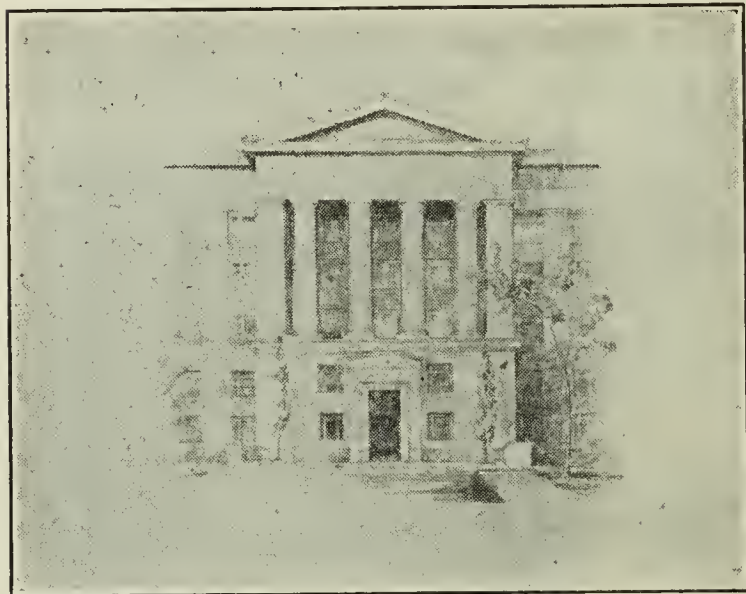
EDWARD R. WEIDLEIN

The System of Research

Before presenting a résumé of the research accomplishments of the Institute in the domain of ceramics, it is pertinent to describe briefly the operation of the Industrial Fellowship System. In accordance with this System, an individual industrialist, a company, or an association of manufacturers, having a suitable problem or group of problems requiring scientific investigation, may become the donor of an Industrial Fellowship, provided that the problems are of sufficient scope to warrant the services of at least one research chemist or engineer for a period of at least one year; and also that there is no other research in progress in the Institute

¹ Director of the Mellon Institute of Industrial Research of the University of Pittsburgh, Pittsburgh, Pa.

on the particular subject which is of interest to the prospective donor. The Industrial Fellowships of the Institute are of two general types: namely, Individual and Multiple. An Individual Industrial Fellowship utilizes the services of one research man (with assistants where necessary),



The Mellon Institute of Industrial Research.

“This building is dedicated to the service of American industry and to young men who destine their life-work to the industries; the goal being ideal industry, which will give to all broader opportunities for purposeful lives.”

who is responsible directly to the executive staff of the Institute. A Multiple Industrial Fellowship has the services of one or more Junior Fellows under the direction of a Senior Fellow, who, in turn, is responsible to the executive staff. As is well known, the Institute is not of a commercial nature, but is entirely independent, and derives no financial profit from the investigations conducted under its auspices.

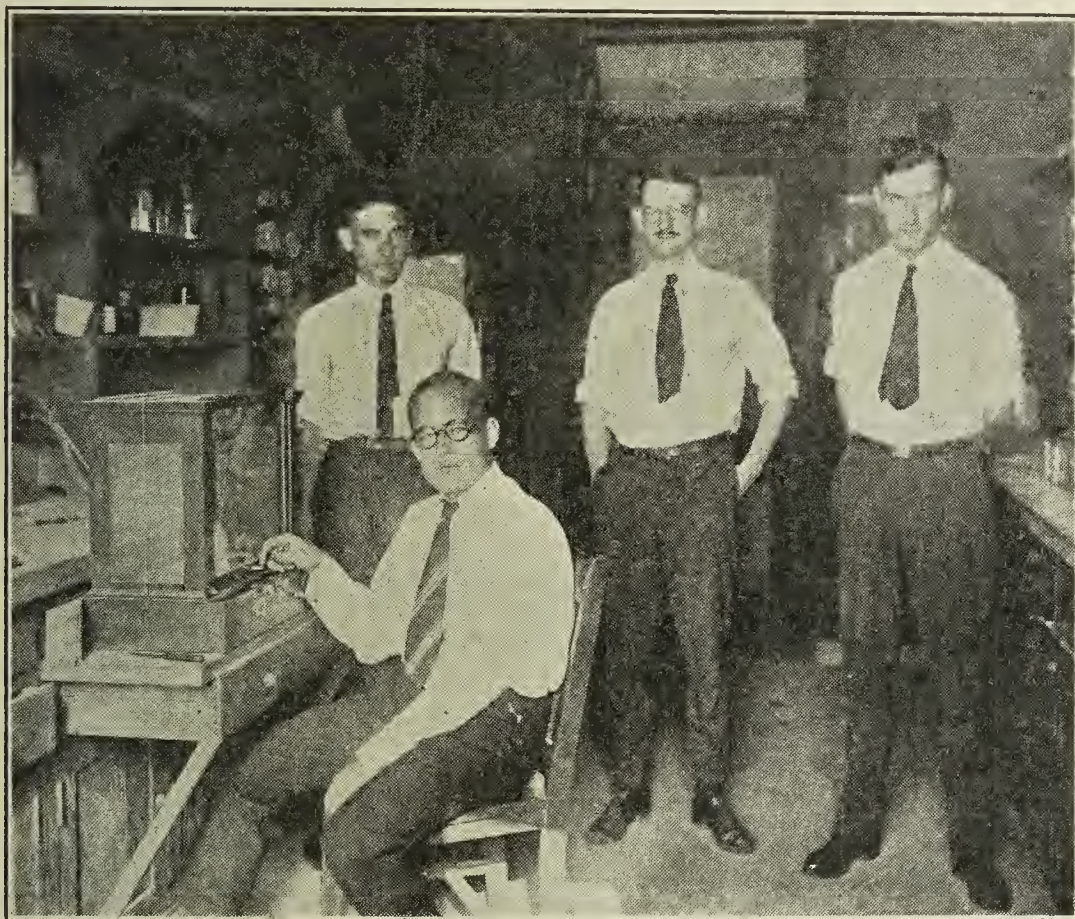
includes operating charges, the purchase of all necessary special apparatus or other equipment, and the salary of the research man or men selected to work on the particular problem, the solution of which is of concern to the donor. It is also essential that the donor extend coöperation by sympathetic encouragement and practical suggestion.

The donor of an Industrial Fellowship provides a foundation sum which is adequate to cover the annual cost of maintenance of the investigation, which includes operating charges, the purchase of all necessary special apparatus or other equipment, and the salary of the research man or men selected to work on the particular problem, the solution of which is of concern to the donor. It is also essential that the donor extend coöperation by sympathetic encouragement and practical suggestion.

The Institute, in turn, provides laboratory, library, and consultative facilities, the use of its permanent research equipment, direction to the progress of the work, and an atmosphere which is conducive to productive investigation. All results obtained by the Industrial Fellowship belong exclusively to its donor.

The Industrial Fellowship System has been in successful operation at the University of Pittsburgh for 12 years, and it has been prominent in making clear to American manufacturers that scientific research, properly planned and systematically carried out under conditions favorable to productive effort, is remunerative to them and actually constitutes an investment. It is now recognized by industrialists that the methods of science are the most effective procedures thus far developed for the advancement of technology, and that, therefore, scientific investigation is an essential economic adjunct to manufacturing enterprises. But this understanding of the meaning and value of research has come in quite

recent years in the United States, for American manufacturers required demonstration of the economic value of scientific investigation. At



The staff of the Multiple Industrial Fellowship of the Refractories Manufacturers' Association. Left to right: W. R. Kerr, R. Ferguson, S. M. Phelps, and R. M. Howe (Senior Industrial Fellow).

present the encouragement of research and the recognition of the desirability of disseminating the knowledge gained are indeed among the most noteworthy signs of progress in technology.

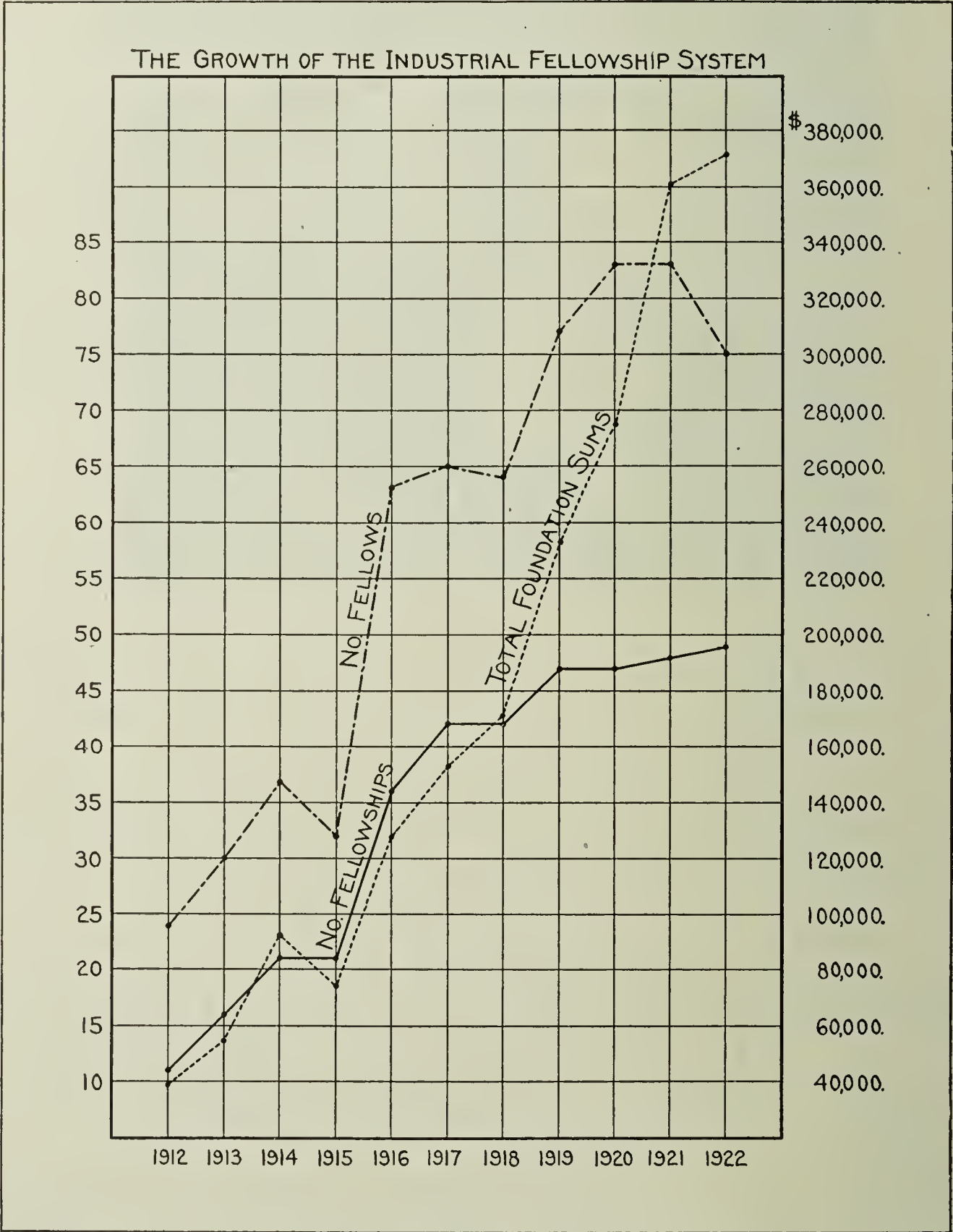
The Growth of the System

There are now (December 1, 1922) 50 Industrial Fellowships in operation and 85 research men are engaged thereon. The development of the System since 1912 is shown graphically in the accompanying figure. The number of Industrial Fellowships has grown from 11 to 50, while the total Fellowship receipts have increased tenfold.

The total amount of money contributed by industrial firms to the Institute for the eleven years ending March 1, 1922, was \$1,955,922. During the same period, the Institute itself expended approximately \$830,000. In addition to these sums, an amount of money now running into several million dollars has been spent by the industries in developing into large scale manufacture various processes worked out at the Institute.

There are now (December 1, 1922) 38 Individual and 12 Multiple Fellowships. The list of these investigations indicates the breadth and

diversity of the Institute's work. Since only one research is carried out on a particular subject at any one time, and since there is accordingly no duplication of the investigational activities of the Fellowships, there



is always a wide variety of different problems under study. Most of the Fellowships are well established in their fields of inquiry; and their renewal, year after year, attests to their research productivity and to the confidence which their donors have in the Institute.

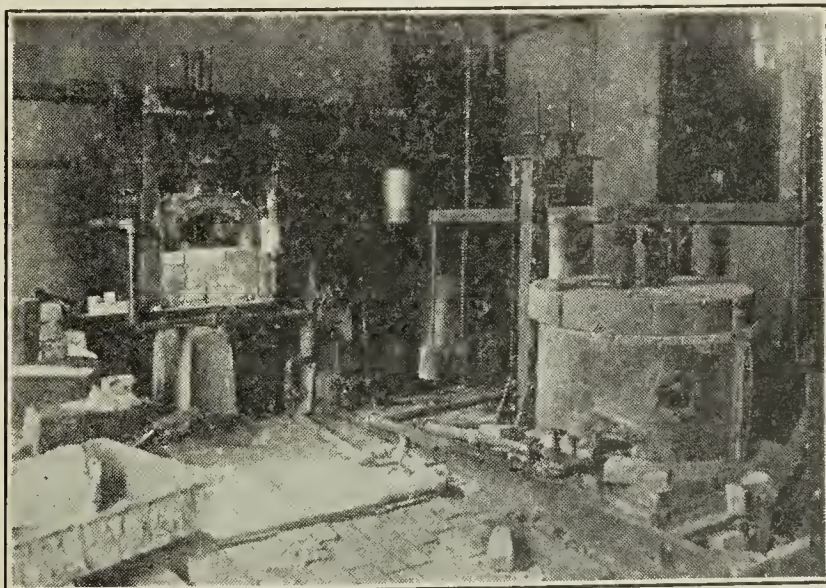
Thirteen Industrial Fellowships have been founded by associations

of manufacturers. These Fellowships not only enable the Institute to be of direct service to groups of industrial concerns, instead of to individual companies, but their successful operation also gives rise to more stable relations of coöperation among the company-members of these associations by the induction of the reciprocal exchange of experience and research results. Four of the association Fellowships are in the field of ceramics.

The author has frequently been requested to give a statement concerning the financial gains which have been derived by donors as a result of the Institute's activities in their behalf. While he is not privileged to release this information at present, it may be mentioned that 85% of the problems accepted by the Institute, 1911-1923, have been solved satisfactorily from the donors' standpoints.

Researches in Ceramics

Dr. Robert Kennedy Duncan, the founder and first director of the Institute, was interested in the infusion of scientific method in glass technology and carried out several inquiries of technical importance in this branch of ceramics. Indeed, ever since its establishment the Institute has been active in research in the ceramic field. These investigations have included glass, enamels, dental cements, refractories, and other clay products. Dr. E. Ward Tillotson, Jr., an Assistant Director of the Institute and distinguished for his researches on the physical properties of glass, is in supervisory charge of the ceramic Fellowships of the Institute. Since it is recognized by the Institute that an industrial research establishment must



Experimental furnaces used in the systematic study of refractories and clay bricks, Mellon Institute of Industrial Research, University of Pittsburgh.

be known by the successful commercial processes which it has developed and by the published accounts of the inquiries which it has carried out, the results of all ceramic studies are reported whenever possible in the *Journal of the American Ceramic Society*.

The first ceramic investigation undertaken by the Institute was a study of the cause of elimination of "strea" (striae) in fine glassware. As a result of this investigation, an improved glass pot was developed (U. S. patent No. 1,200,889, October 10, 1916, of Dr. S. R. Scholes) which has

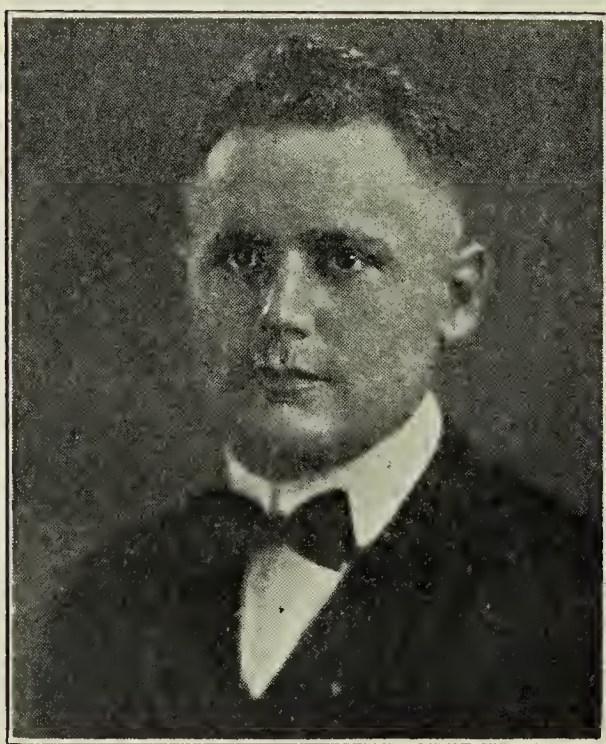
proved to be of value for the heavy potash-lead glass employed in making fine tableware.

A second glass investigation, conducted by Dr. R. R. Shively, was devoted to translucent glass employed in lighting ware. Among the important developments of this inquiry was the production of a low-expansion translucent glass of superior heat-resisting properties and possessing unusual light transmitting and diffusing properties.

Studies of tank-furnace operation and control for the production of glass for automatic machines have been made by Dr. R. R. Shively and by Dr. J. F. W. Schulze.

Two investigations on enamels, one for sheet steel and the other on cast iron, are in operation at the present time. The sheet-steel Fellowship, of which Mr. R. D. Cooke is the incumbent, has been in operation since 1917. The published reports of his investigations are confined to two United States patents, Nos. 1,316,018, of September 16, 1919, on "Manufacture of Enameled Ware," and 1,272,917, of July 16, 1918, on "Removing Enamel from Enameled Metal Articles." Mr. J. E. Hansen is completing the third year of an investigation of enamels for cast iron.

Dr. C. C. Vogt, in an investigation of silicate dental cements extending over a period of three years, made discoveries which have enabled the production of an improved dental cement or "enamel." Dr. Vogt has presented certain of his results in a paper entitled "The Chemistry of Silicates and Their Application in Dentistry."¹



H. G. SCHURECHT

Since 1915 there has been in progress an investigation on refractories supported by the Refractories Manufacturers' Association. Reports on several specific problems have been published by Mr. R. M. Howe, Senior Incumbent of this Industrial Fellowship, and by his co-workers. In addition to many improvements in the manufacture of refractories, Mr. Howe has accomplished much in coöperation with the A. S. T. M. in standardizing the testing of refractories. During the period of 1919 to 1921, Mr. Mark Sheppard carried out successfully a study of the manufacture of zirconia refractories. While a complete report of his findings

has not yet been published, the commercializing of them is dependent only upon economic conditions.

¹ *Journal of the National Dental Association*, 5, 354-73 (1918).

Mr. H. G. Schurecht has lately commenced an exhaustive study of vitrified clay products under the auspices of a large group of manufacturers of sewer pipe and drain tile. The program of this investigation is an ambitious one and involves the study of fundamental problems as well as problems in technology.

This, in brief, is what the Mellon Institute has done and is doing in research in ceramics, a branch of technology in which the Institution is vitally interested, not only because of its location in a district which has a dominant position in the manufacture of glass, face brick, refractories, and similar ceramic products, but principally because of the essentiality of effecting advances to keep pace with the requirements of users of ceramic products. Until comparatively recent years progress in ceramic technology had been with a halting step, but that period has passed and now all important branches of the great ceramic industries are cognizant of the high technical value of scientific research carried out for their benefit.

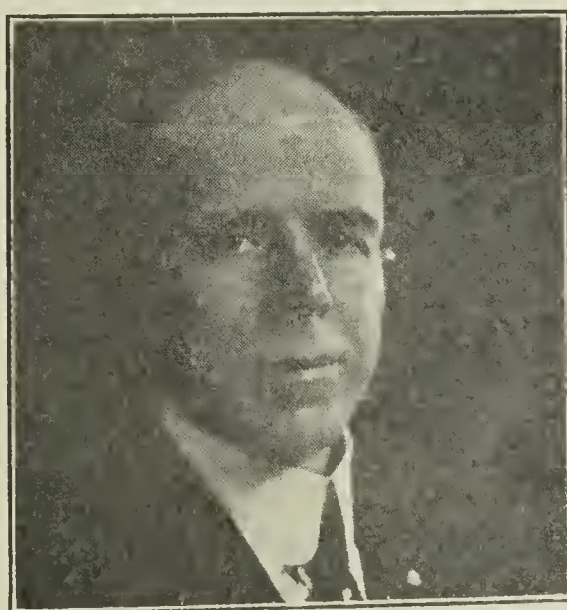
MELLON INSTITUTE OF INDUSTRIAL RESEARCH
UNIVERSITY OF PITTSBURGH
PITTSBURGH, PENNSYLVANIA

THE PITTSBURGH TESTING LABORATORY IN THE CERAMIC FIELD

BY JAS. O. HANDY

A research and testing institution such as the Pittsburgh Testing Laboratory, established in 1881 in a district already a center of the glass, pottery, enameling, cement and clay-working industries, naturally has given special attention to the problems of these various branches of the ceramic industries.

In the field of glass manufacture investigations have been conducted for the makers of plate glass, window glass, illuminating glassware, table glassware, and optical glass. Defects such as stones, seeds, discoloration, seams, strains, etc., have been traced to their sources in the use of improper or too coarse materials, improper temperature control, insufficient gas evolution at the proper time during melting, and improper annealing technique.



JAMES OTIS HANDY

Batch formulas have been revised and in many cases it has been found possible to make better glass at less cost than at the beginning of the investigation. We have found it quite customary to use excessive amounts

of expensive materials in the batch without real benefit and even with actual damage to the quality of the glass. Close studies of apparatus used for sand grading in plate glass manufacture and for the machine blowing of window glass have been made.

In the illuminating glassware industry the Laboratory has been closely associated with the development of the so-called "semi-translucent" glass which permits the passage of a large percentage of the light from the electric filament without the phenomenon common to opal glass and known as "fire."

In the field of enameling cast iron and steel the Laboratory has been called upon to investigate troubles caused by crazing, chipping, etc., and



to prepare less expensive enamels while still maintaining high quality. This work has been quite successful, particularly in the cast iron enameling industry.

Enamels are exceedingly complicated mixtures of silicates, borates, and fluorides, and the maintenance of uniformly good quality requires close attention. Many of the large articles which are enameled vary greatly in thickness and shape so that the production of an even and highly lustrous coating of enamel over such varying surfaces is a real art.

In the manufacture of basic refractory materials the Laboratory has assisted in the development of granular coated dolomite which during the

war emergency successfully replaced the imported granular magnesite for use in the construction of basic open hearth furnace bottoms. This material is made in rotary kilns, and while the process as developed is a very simple one, it required a great deal of experimental work before it was perfected. Properly made, granular coated dolomite resists the action of atmospheric moisture for long periods of time so that it may be kept in storage for a considerable time before it is used. Finally, its coating of basic slags assists in the binding together of the granular materials in the furnace bottom, and makes a more permanent bottom and one which can be prepared in a shorter time than one made from magnesite.

In the hydrated lime industry it is sometimes a problem to make from certain limestones or dolomites a hydrated lime which has the required degree of plasticity or spreading qualities. The experiments have succeeded in making such hydrated lime from raw materials not normally yielding the desired product.

In the gypsum products industry the manufacture of Keene's cement was the subject of investigation. Magnesium oxychloride or Sorel cement products have been made and tested.

Portland cement concrete failures have been the subject of many investigations.

For the convenience of the ceramic industries we maintain in Pittsburgh laboratories equipped with facilities for testing ceramic materials both in the raw and finished states, and by both chemical and physical methods.

Gas and electric furnaces for making vitrification and fusion determinations and load tests are available, and there are facilities for burning experimental lots of clay or shale and limestone intended for cement manufacture.

Limestone, dolomite, magnesite, fire clay, feldspar, fluorspar, silica rock, gypsum, Portland cement, etc., are all being tested in different ways and at frequent intervals.

The personnel of our chemical department is as follows: J. O. Handy, Director of Special Investigations, H. H. Craver, Manager of the Chemical Department, C. E. Betz, Chief Chemist, and a corps of assistants.

PITTSBURGH, PA.

FOREIGN CERAMIC SOCIETIES

England, Germany and Japan have Ceramic Societies which have the same scope and purposes as has the AMERICAN CERAMIC SOCIETY. Nearly every manufacturing country has technical societies and journals devoted to particular industrial ceramics and also national commissioners and surveys which make ceramic investigations. The British Government probably has done more to encourage industrial research by organized groups than any other country. It is safe to say there is no ceramic group of commercial importance in any country that does not have a federation of ceramic manufacturers engaged in technical and scientific research.

It was the aim of this review to have a sketch of the organized research activities, of the press and of the schools devoted to ceramics in each of the foreign lands. That there are omissions in the account here given is due neither to want of effort to secure this information nor to the desire on the part of fellow craftsmen in other lands. Shortness of time was the defeating factor.

THE CERAMIC SOCIETY

BY JAMES A. AUDLEY

In attempting to trace the progress made in ceramics in the British Islands during the past twenty-five years or so, it may at once be stated that for a long period before the commencement of the present century very little had been done in the way of systematic research. Indeed no facilities for such research had existed either in educational institutions or factories since Wedgwood's time.

The first regular course of lectures bearing on ceramics appears to have been delivered at the Potteries Mechanics' Institution, Hanley, by the late Dr. Thomas Carnelley (afterwards Professor of Chemistry, first at Dundee and later at Aberdeen), who travelled specially from the Owens College, Manchester, to give one lecture every other week. This was in the late seventies, the course of lectures being on "The Chemistry of Pottery." It was not until the autumn of 1884 that the first regular class in "Pottery and Porcelain Manufacture" was started in the district, at the same Institution in Hanley, by the late Mr. Miles Knowles, Head Master of the Tunstall Endowed School, who, as Science Master at Hanley, had previously conducted evening classes in science. A year later a similar class was established at the Wedgwood Institute, Burslem, by the late Mr. S. J. Harris, who soon afterwards, with the aid of Mr. H. Watkin, arranged a simple course of practical exercises to supplement the lectures. The practical work greatly promoted the success of the classes, but there was still nothing that could be styled systematic research. In 1890 (when Mr. Harris left the district) Mr. Watkin took sole charge, but later he had

for several years the assistance of Mr. H. E. Wood, now (1922-23) president of the Ceramic Society. In 1899 the late Mr. W. Jackson was appointed instructor of the pottery classes, which for convenience were transferred from Burslem to the Victoria Institute, Tunstall, where a laboratory was specially equipped for practical work in pottery and porcelain manufacture. Mr. Jackson resigned towards the end of 1904 and accepted an appointment with a local firm of manufacturers. Early in 1905, Dr. J. W. Mellor was appointed to fill the vacancy and carried on the good work. Near the end of 1908 a large temporary structure of iron and wood was erected near Stoke Railway Station to accommodate the pottery classes which were transferred from Tunstall. Here great progress was made until 1913 when the pottery department in charge of Dr. Mellor was more worthily housed in a commodious permanent building close by in which were combined exceptionally good facilities for both teaching and research. Thus in baldest outline is indicated the course of development of facilities for ceramic educational and research work in North Staffordshire which may be regarded fairly as the ceramic center of the kingdom.

It has been mentioned that Mr. Jackson took charge of the pottery classes in 1899, with the advantage (over his predecessors) of a specially fitted laboratory for practical work. A natural consequence of this was that it soon became possible for some of their more advanced students to apply their knowledge and experience by carrying out investigations under Mr. Jackson's guidance. Moreover, the informal discussions of their problems at the school led to the suggestion of holding periodical meetings for dealing more fully and systematically with various questions of interest as they arose. In this way originated "The North Staffordshire Ceramic Society" which appears to have commenced in 1901 with Headquarters at the Victoria Institute, Tunstall. In 1903, the name was changed to "The English Ceramic Society" and in 1916, it was again changed to "The Ceramic Society" so as not to conceal the cosmopolitan character of its membership. The Headquarters of the Society passed over to Stoke along with the chief pottery school.

From what has been stated it seems clear that Mr. Jackson may properly be called the founder of "The Ceramic Society." Mr. F. Hodgkinson was Secretary for the first year and was succeeded by Mr. Jackson who continued to hold that office until 1905 when he was elected President. Mr. Jackson was for some years a regular contributor to the *Transactions* but with diminishing frequency after 1909. After leaving the Tunstall Pottery School Mr. Jackson's services were secured by the late Mr. Alfred Meakin for his factory at Tunstall. On Mr. Meakin's decease a few years later Mr. Jackson went to Minton Hollins and Co.'s Patent Tile Works at Stoke. Ill health afterwards compelled him to retire from pottery work. His health being restored he took up Government work during the War

at Hadfield (Lancashire) as a superintending technical chemist, being engaged in the purification and preparation of cotton for use in making cordite and other war munitions. He also conducted classes in chemistry at Rossendale and other places. When the War ended Mr. Jackson acquired a glass and china business at Bury. He was associated with Mr. J. P. Holdcroft in the invention of the thermoscope so much used in connection with the firing of pottery. In early years Mr. Jackson won a Scholarship at the London Royal College of Science and afterwards gained a Scholarship at Zurich University. On returning to England he became Science Master at the Victoria Institute, Tunstall. He died on January 10, 1921 at Stacksteads near Manchester.

Of those who were associated with Mr. Jackson in the inauguration of the Ceramic Society, mention has already been made of Mr. H. Watkin and the President (Mr. H. D. Wood) both of whom have figured in the list of contributors. Mr. Watkin is identified with the firm of James Macintyre & Co. Ltd., Burslem, and is well known for the heat recorders which bear his name. Mr. Wood has had a long and honorable connection with the Burslem Pottery of Messrs. Doultens, Ltd., and has maintained a keen interest in the Society all along. In the first volume of *Transactions* appears a paper by him on "Bone in English China." Other contributors to this volume were the late Mr. W. P. Rix, Mr. Arthur Lovatt, and Mr. R. H. H. Jones. The last named was treasurer from the start until 1916 when he left Staffordshire to take up the management of a works in Devonshire. In the first volume also appeared some abstracts made by Mr. Jackson from several German periodicals.

The first president was Mr. William Burton, widely known for his valuable books on pottery subjects and formerly managing director of Messrs. Pilkington's Tile and Pottery Works at Clifton Junction near Manchester. He was succeeded as president by Mr. Bernard Moore well known as an accomplished practical potter and by his valuable contributions to the *Transactions*. Next followed Mr. J. P. Holdcroft formerly a pottery manufacturer but for many years past a brick maker and manufacturer of the familiar Holdcroft thermoscopes and then Mr. Abraham Fielding a well known pottery manufacturer at Stoke. Then came in turn the late Mr. W. Jackson, the late Mr. F. Rawdon Smith and the late Mr. L. Solon the latter being the world famous pottery artist who accumulated a fine collection of books and pottery and whose sons occupy important positions in the ceramic world.

Returning to the consideration of the earliest members, other noteworthy names are those of Messrs. Asaph Leese, A. G. Richardson and F. Turner. The two latter not only contributed to the *Transactions* from time to time but for a number of years they rendered valuable assistance as teachers in the local pottery classes. Mr. Leese who has been throughout one of

the most regular attenders has also been a contributor of papers at various times and was elected President in 1916. Another original member who has contributed freely and retains keen interest in the Society is Mr. Arthur Heath whose capacity for organization has often proved of great value to the Society in connection with excursions, etc. He is personally known to many members of the AMERICAN CERAMIC SOCIETY.

Turning now to later years it needs no demonstration that under the direction of Dr. Mellor as secretary of the Society and as Head of the Pottery School at Stoke (as well as in other capacities) the increased facilities have resulted in an enormously expanded output in the shape of results of investigations in almost every department of pottery work. A constantly growing band of capable well-trained students and assistants are ever resolutely attacking problems new and old in a systematic way under the direction of their chief and in this way is being accumulated a vast store of information and valuable data for the use of all who know how to apply such knowledge to practical advantage.

As previously noted a few abstracts from foreign journals appeared in the very first volume of the *Transactions*. Unfortunately no more are to be found until Volume VI is reached, but here they were taken up at Dr. Mellor's instigation on a much more extensive scale, the sources being various German, French, American and British journals. Henceforth with the exception of Volumes VI and XV abstracts were published in every volume issued. For some years the abstracts represented the voluntary work of a number of members. Then for several years they were prepared by the International Institute of Technical Bibliography. In 1917, it was decided to engage a part time abstractor to prepare the abstracts and finally, in 1920, a full time abstractor was engaged.

In 1916, the Governors of the Central School of Science and Technology at Stoke acquired the late Mr. L. Solon's ceramic library reputed to be at the time the finest and most nearly complete collection of ceramic publications in existence. It includes many rare items and is housed in the same room as the Ceramic Society's library.

It is of interest to note that eight meetings of the Society were held in the first year with an average attendance of fifteen out of a total membership of thirty. In the second year there were nine meetings and fifty-four members with average attendance of twenty-two. Nine meetings were also held in the third year, the membership being sixty-eight and the average attendance 23.5.

A very important development took place in December, 1916, when the Refractory Materials Section of the Society was established. This was not instituted too soon for before the War nearly all the magnesite bricks for basic steel furnaces and other purposes came from Austria and new sources of supply had to be found quickly. Moreover, various other re-

fractories were needed in increasing quantities and the aggregate output had to be greatly expanded. Part of this increased output was needed to send to neutral countries in exchange for essential materials and part for allies. The Society had not altogether neglected the subject of refractories previously for papers bearing on some aspects of the subject had appeared from time to time in the *Transactions* but very little organized research work in this direction had been undertaken, there being practically no funds available for the purpose. Nevertheless, a certain amount had been taken up at Stoke by Dr. Mellor and his assistants and at Leeds University by Professor J. W. Cobb and his co-workers. Both of the gentlemen just mentioned have continued to direct important researches on various materials, old and new. This development brought a large number of new members to the Society but the Refractory Materials Section has maintained a semi-independent organization with its own Council though the same Secretary and Treasurer have always acted for both the parent Society and its vigorous offspring. Another striking consequence was a great widening of the field for abstracts.

Among the outstanding figures connected with the Refractory Materials Section besides those already named may be mentioned Sir William J. Jones, formerly of the war-time Ministry of Munitions, and Lieut.-Col. C. W. Thomas of Stourbridge each of whom has occupied the presidential chair.

Another development of somewhat later date perhaps deserves more than a passing mention. The art side of ceramics only cropped up incidentally on very few occasions. The first systematic attempt to discuss this aspect of the subject was by Mr. J. Eyre in March, 1917, his paper being entitled "On the Necessity of Science and Art in Modern Pottery Manufacture." It appeared in Volume XVI of the *Transactions* (1916-17). In January 1918, Mr. A. E. Gray read a paper on "The Encouragement of Art in the Potteries" which is printed in Volume XVII of the *Transactions* (1917-18). This led in a very short time to the establishment of an Art Section with its own officers and council. This Art Section has done considerable propaganda work by means of lectures and discussions, exhibitions of paintings and other works of art, exhibitions of modern pottery, etc.

Thanks to the results attained in very large measure through the activities of the Ceramic Society and its Refractory Materials and Art Sections, there can be no doubt that the ceramic industry now rests on a much firmer basis than it did twenty years ago. Much of the old-time mutual distrust and suspicion among manufacturers has gone and there is a wide-spread desire to promote systematic investigation by competent observers. The continued existence of such an atmosphere would be the best security for further progress. The Ceramic Society should be in future, as in the past, a radiating center for such progress.

THE SOCIETY OF GLASS TECHNOLOGY

BY W. E. S. TURNER

During the summer of 1916, the students attending the various local center courses in Yorkshire conducted by the Department of Glass Technology, University of Sheffield, had two or three pleasant joint meetings when, after a visit to some works and subsequent social intercourse, more or less informal discussions were held on some problem connected with glassmaking. It seemed to the writer that these meetings might well be put on a more permanent basis.

There existed no scientific society which made any appeal to the average glass manufacturer and it was felt that to have such appeal, any society formed must deal with the subjects near his heart and concentrate on them. Not only was there no scientific society but there was no organization at all which brought together all persons interested in the industry. It was, indeed, discovered during the early meetings of the Society that many well-known manufacturers had never met one another although known by name to each other for years. Under such conditions it was not surprising that a meeting called at the University of Sheffield in October, 1916, received the idea of a society very favorably and after necessary preliminaries the Society of Glass Technology came into existence at a meeting on November 9, 1916.

The new Society arrived at an opportune moment and enthusiasm ran high. Membership was not made exclusive, the main condition being a desire to promote the advance of scientific study connected with glass-making. In the words of the Society's Constitution, the objects were: (a) The association of persons interested in glass technology. (b) The general advancement of the study, science, and general practice of glass technology.

Three classes of members were recognized, namely, (1) collective, (2) ordinary and (3) student members. More recently, a class of honorary members has been established. The following figures of membership show the growth of the Society:

1916-17	264
1918	391
1919	516
1920	620
1921	663

Of the 663 members on the roll at the end of 1921, 142 were collective and 516 ordinary members.

Although the headquarters of the Society were established at Sheffield, the University authorities kindly offering accommodation, it was believed to be in the general interest that the monthly meetings should be held

at different centers of the industry in order to stimulate local interest. Further, in order to emphasize the national character of the work, despite its origin in Yorkshire, the officers of the Society were deliberately chosen so as to give as wide a representation as possible to the different glassmaking centers.

Under the influence of the Society, a change took place in the mental outlook of the industry. The country was at that time united in a common purpose to win the War. There was, therefore, a disposition towards coöperation which naturally grew as competition from abroad grew less and less and internal competition grew slack in the face of the heavy demands on the industry. But if there were these influences in favor of discarding the intense secrecy, long a tradition in the industry, it was the work of the Society which, by the establishment of cordial relationships and even personal friendships among members of the industry, made possible an exchange of information and willingness to give as well as to take. One result was soon seen in the way in which manufacturers consented to admit parties of members of the Society to their works without limitation. The spirit thus born has continued to live. In times of severe trade depression like the present there may be less inclination to admit into works possible competitors, but the writer believes the industry will never again go back to its ruts and its troughs, cherishing secrets which are not worth cherishing.

The publication, which began in May 1917, of the *Journal of the Society*, soon began to make the Society's work known outside the United Kingdom and the Society had the pleasure of welcoming applications from overseas, and particularly from friends in the States. Out of the membership of 663 registered at the end of 1921, 169 were resident outside Great Britain and Ireland. The proportion of overseas members is bound to grow as time proceeds and the Council trusts that these overseas members will not merely take, but will begin also to contribute, by papers and discussion, to the Society in which they enjoy membership.

Up to the present time, the Society's activities have been largely devoted to the dissemination of knowledge through the reading and publication of papers and by the educating influences of mutual knowledge among the glass manufacturers. The Society's subscriptions are so small that no funds have as yet been available for subsidizing researches; but there is no doubt that the influence of the Society's work has greatly strengthened existing research institutions and made possible also the founding of the Glass Research Association; while there is equally no doubt that the Department of Glass Technology in the University of Sheffield has stepped in time after time, when other papers for discussion have not been forthcoming, to furnish the results of researches and create topics for discussion.

Undoubtedly, as the Society gains in strength financially, its support of researches will become an important element in its work. In 1918, the British Ministry of Munitions, realizing the urgent need of improving glasshouse refractory materials, entrusted the Society with a grant of £1000 and told it to go ahead. The result was the issue of the Provisional Specifications for Glass Refractories, while the Department at Sheffield was subsidized to carry out extensive researches, now published, on fire clays.

The Society has committees of an advisory character, namely, the Refractory Materials Research and Specifications Committee, and a committee on Glass Standards. It also coöperates with other bodies having like interests. The Society is preparing a Directory for the British Glass Industry. This does not strike one as connected with scientific research but it is work that has long required to be done and this is the one reason which has impelled the Society to undertake it.

In view of the special occasion for which this article is written, it would not be paying an acknowledgment we feel due, if the writer did not say how much our own glass industry and our own Society has been stimulated and influenced for good by progress in America and by the work of the AMERICAN CERAMIC SOCIETY. Our members will never forget their visit of 1920 and other members who have paid individual visits have told the writer how impressed they have been both by the kindness shown to them and the education in new methods they have received in America. Friends in America have, on the other hand, told the writer at times of the respect they have for the work of our own Society. May this mutual respect, founded on the belief that we are both doing our best for the advancement of silicate technology and endeavoring honestly to be of service to our fellows, grow more and more during the next five and twenty years.

THE UNIVERSITY OF SHEFFIELD, ENGLAND

TEACHING AND RESEARCH IN GLASS TECHNOLOGY AT THE DEPARTMENT OF GLASS TECHNOLOGY, UNIVERSITY OF SHEFFIELD

BY W. E. S. TURNER

Among the many deficiencies revealed by the War was the absence of any provision in Great Britain for instruction or research in the subjects comprised under the general heading of Glass Technology. True it was that for some years the City and Guilds of London had issued the syllabus of a scheme of instruction and at one center, namely, Wordsley, under Mr. Stourbridge, a class had been run at the local technical school, being attended, however, more frequently by the glass decorators than by the glass-house workers.

A survey made early in 1915 by the writer showed clearly how sadly neglected the industry had been by organized scientific bodies and how very deficient, on the other hand, were the glass manufacturers themselves even in the rudiments of scientific knowledge. It was also found that almost on the doorstep of the University at Sheffield there was a large and important glass industry, namely, that of the West Riding of Yorkshire. So strong a case was made out for assisting the industry that the duty of the University seemed clear and the Council had little hesitation in deciding to found the Department of Glass Technology for the express purpose of providing courses of instruction and facilities for research. Mr. H. A. L. Fisher, then Vice-Chancellor of the University and later Minister for Education in the Government, was a very strong supporter of the scheme. The writer was invited to take in hand the organization of the Department.

The Department was not content to wait for students to come to it. It had a mission for those in the industry who could not come; and local center courses, providing very elementary courses for the workers, were established in several centers of the industry in Yorkshire and attracted numerous students varying in age from 18 to 60. The courses were progressive, a complete course lasting three or four years; moreover, as the news spread of what was being done in Yorkshire, other centers were started in other areas, and classes of this type have been held in Derby, London, Alloa, Glasgow and Newcastle, in addition to the Yorkshire centers (Barnsley, Castleford, Knottingley, Leeds, Mexborough, Morley, Sheffield and York).

At the University itself, a three years' Diploma course was at first set up; but it was soon found that the subject of Glass Technology must be accorded full recognition in the University curriculum and in 1918 it was made a full degree subject, while further, in 1920, an Honors School was established. The courses are open to all students, whatever their country or origin; and, indeed, students have come from many parts of the world. Postgraduate students are especially welcomed and the research facilities enabling graduates of British and foreign Universities to work for the degree of Ph.D. are ample.

While the initial expenses of the Department and much of the later expense have been borne by the University direct, several bodies have made contributions. In 1915 a Committee of the Privy Council of the Government was set up for the express purpose of fostering industrial research, and from that body a capital grant for equipment of £1,500 was obtained, together with an annual grant for five years of £1,200. The capital grant was made conditional on the glass manufacturers themselves also subscribing; and grants from the Yorkshire Glass Bottle Manufacturers' Association, the Yorkshire Flint Glass Manufacturers' Association, and

later also, the Association of Glass Bottle Manufacturers' of Great Britain and Ireland, each of £1,000, made it possible to erect a small building on a site purchased by the University. This building contained a lofty glass melting room 55 ft. x 35 ft. with other rooms for storing and mixing batch, pots, and machinery, and a lampworking room. In 1917, the Ministry of Munitions, Optical Munitions branch, provided a further £3,000 for equipment, in view of the Department doing special work for the Ministry.

A big expansion of premises was decided on in 1920. For some time, the growing activities of the Department had found the original premises becoming too small and it was decided to expand if the necessary funds could be raised. In 1920 it was also decided to undertake certain melting work for the newly-formed Glass Research Association. Sufficiently adequate facilities did not exist to carry out the operations on the large scale required and immediate expansion of the existing premises being then beset by difficulty, an offer of sale of a local glass works was taken advantage of. Towards the purchase of the works, glass manufacturers subscribed about £7,000 while the University showed its friendship to the industry by furnishing several thousands more for completing the purchase and for commencing to equip the premises. The severe trade depression which began at the end of 1920 prevented the scheme of equipment from being more than partially realized. The buildings, however, which, after modification, comprize a set of laboratories, large pot rooms and mixing rooms, two glasshouses and auxiliary buildings, are sufficiently large as to give ample room for further development when funds are available. The glass melting facilities are extensive and make it possible to produce glass in quantities varying from the thimble full to a 1000 lbs. For the last-named, there is a two-pot recuperative furnace fired by producer gas. In small quantities, the meltings are carried out by town gas or by electric heating.

In addition to the teaching activities already mentioned, there are three others which must be outlined. The first was the setting up in 1917 of a Lampworking School to train bench glassblowers for an industry which practically had to be created after War broke out. Boys, girls, and disabled soldiers were trained for this work, 92 in all receiving courses of training and practically all of them being placed in situations. Inventions to burners, in semi-automatic lampworking machines, and in graduating apparatus were also made. Owing to trade depression and lack of funds the School had definitely to be closed in July, 1922.

Next, the Department has long served as a center where manufacturers can bring their troubles, and scarcely a day passes without one or more inquiries for assistance in some form or other coming in. Tests, varying from the examination of raw materials to investigations involving numerous

meltings of glass are regularly made for manufacturers privately who bear the cost. Investigations of wide scope are at present also carried out for the Glass Research Association.

Finally, fundamental researches in glass technology are recognized as one of the main objects for the existence of the Department and between 1917 and the date of writing (October, 1922) 68 papers and reports embodying research on a great variety of subjects have been published, in addition to those which pass direct into the hands of the Glass Research Association and are published in the Bulletin of that Association. The members of the staff of the Department also are mainly responsible for preparing the abstracts of papers which appear in the *Journal of the Society of Glass Technology*.

Over the interests of the Department there presides a body called the Glass Research Delegacy. It is constituted in approximately equal numbers of University representatives and the nominees of glass manufacturers' associations and other interested bodies. The Chairman is Sir Albert Hobson, J.P., LL.D.; Vice-Chairman, Mr. Frank Wood, C.B.E., B.Sc.; and Secretary, Mr. W. M. Gibbons, M.A. (who is also the Registrar of the University). The funds for maintaining the Department come from a variety of sources: from the University Council, the West Riding of Yorkshire County Council, manufacturers' associations, students' fees and donations. Quite a large proportion of the income is derived from work done both for the Glass Research Association and for individual manufacturers.

THE UNIVERSITY OF SHEFFIELD, ENGLAND

INSTITUTE OF CHEMISTRY GLASS RESEARCH COMMITTEE, 1914-1922

BY RICHARD G. PILCHER

At the outbreak of War, meetings of chemists were held under the auspices of the Institute to consider the steps to be taken to insure a continued supply of chemical glass and porcelain apparatus, filter papers, and analytical reagents which had previously been almost exclusively obtained from abroad.

An Advisory Committee of the Institute was appointed to supervise research on glass at the expense of the Institute with a view to arriving at suitable formulas to be available to manufacturers who were willing to assist in maintaining the supply of glass apparatus.

The first formula was produced mainly as the result of experiments of Sir Herbert Jackson and Dr. T. R. Merton on November 30th, 1914, for an alumina-soda glass suitable for the manufacture of chemical labora-

tory ware. This was sent to firms likely to be interested in the industry.

Varieties of foreign glass were analyzed, and the Committee received further formulas from Professor Jackson, as the main worker under the scheme, of substitutes for Jena glass, and, in addition, a formula for the manufacture of miners' lamp glasses of which a very large number, probably two millions, are used annually in this country. At the same time, independent workers including Messrs. Baird and Tatlock, London, Professor H. B. Baker, and Mr. F. W. Branson devised formulas for batch mixtures which were used by manufacturers.

The work of the Glass Research Committee of the Institute continued practically throughout the War. As it progressed, the expenses involved became considerable and the Institute obtained substantial financial assistance from the Department of Scientific and Industrial Research before eventually the work was merged almost entirely under the Ministry of Munitions.

In April, 1915, eleven formulas for various purposes were sent to manufacturers and published in the scientific and technical press with the result that they were even reproduced in Germany. From that time, however, the British manufacturers made good progress with the production of laboratory glass as well as with miners' lamp glasses, glass for X-ray tubes and for other purposes. Other formulas were published by the Institute from time to time until the glass production came under the control of the Ministry of Munitions, after which the formulas were reserved for the use of selected manufacturers. Altogether more than 70 formulas for batch mixtures, including varieties for optical and other purposes, were produced by Sir Herbert Jackson. They included glass suitable for electric light bulbs, opal glass, thermometer glasses, glasses for the manufacture of artificial human eyes, resistant lamp chimneys, milk bottles, vessels for preserving food; and enamels for sealing different kinds of metallic wire into glass, and soft black glass for filling in the caps of incandescent electric lamps.

The work was continued under the joint auspices of the Ministry of Munitions and the Glass Research Committee of the Institute of Chemistry until practically the date of the Armistice, since when the Committee has become merged in a Special Purposes Committee of the Institute which deals with matters affecting the laboratory requirements generally of chemists.

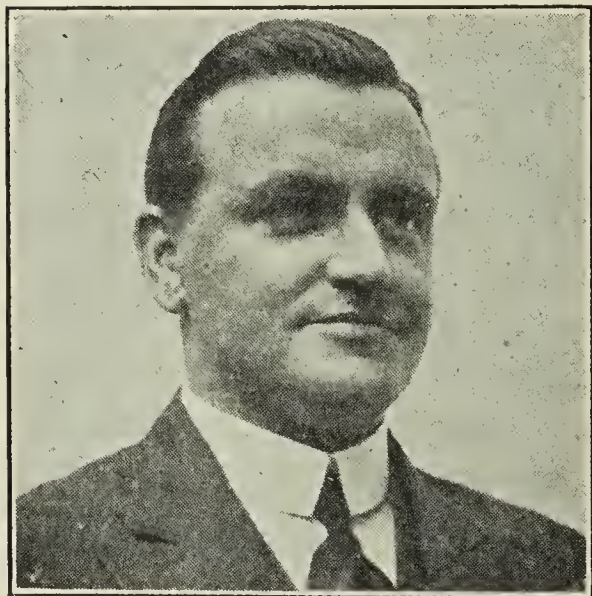
GLASS RESEARCH ASSOCIATION

BY EDWARD QUINE

The Glass Research Association was established to investigate into the problems of the glass industry in accordance with the scheme of the Committee of the Privy Council for Scientific and Industrial Research.¹ The Association received its Certificate of Incorporation on August 11, 1919, and held the first general meeting on October 14th following.

The objects of the Association are to conduct scientific and technical investigations relating to glass and its manufacture, and to disseminate among members technical and other information bearing on these subjects and on the production of articles made wholly or partly of glass.

In order that the industry may attain a high degree of efficiency, it is necessary for investigations to be directed towards overcoming difficulties, in the matter of technique, works organization, production and equip-



EDWARD QUINE, Secretary, Glass Research Association.

ment, in addition to investigations of fundamental principles and search for new knowledge. To ensure greater economy in production and more satisfactory products, improved methods must be introduced, and the works practice of the industry brought into line with the advanced methods found operative in other countries. Until recent years no comprehensive research work relating to the industry had been carried out in this country, but the need for a deeper and more extensive knowledge of the fundamental facts underlying the various processes of manufacture is now appreciated.

The Association is consequently endeavoring to investigate the fundamental principles and their application by systematically conducted researches, so that, side by side with the modernizing of works practice, and the introduction into the industry of the scientific control of the various operations, new knowledge may be developed to the point of plant application.

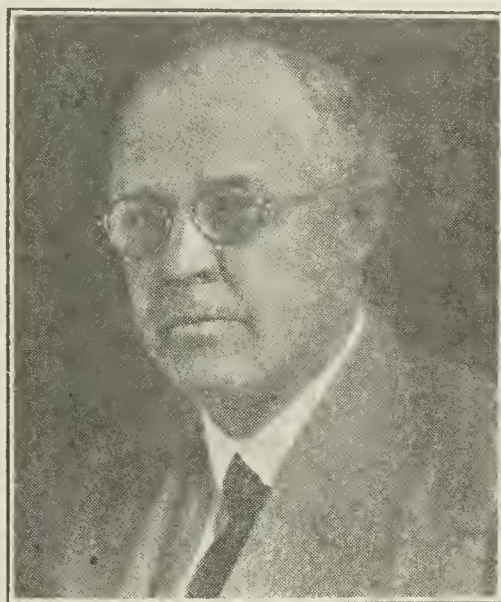
The investigations of the Association cover the problems of all sections of the glass industry other than those of optical glass research work which is being undertaken by the British Scientific Instrument Research Association.

The membership of the Association is limited to British corporations and British subjects carrying on business in connection with the manu-

¹ *Bull. Amer. Ceram. Soc.*, 1 [11], 326(1922).

facture of glass, and other trades and industries allied therewith or accessory thereto. Individuals ineligible for membership or not desiring admission as members, who are interested in the glass industry and willing to subscribe to the objects of the Association, may be admitted by the Council as associates.

The management of the Association is vested in the Council with an Executive Committee; the Council consists of a majority of elected members together with a limited number of members co-opted because of their special knowledge and experience, and members nominated by the Department of Scientific and Industrial Research. The Chairman of the Council is Mr. George E. Alexander, O.B.E., whose in-



ROBERT L. FRINK

valuable support and direction have been largely responsible for the successful establishment and progress of the Association.

The organization and direction of research work is entrusted to a Director of Research, and the Association appointed to this post Mr. R. L. Frink, formerly of the Frink Laboratories, an active member of long standing of the AMERICAN CERAMIC SOCIETY, who took office on the 1st of March, 1920.



GEORGE E. ALEXANDER, O.B.E.,
Chairman Glass Research Association.

The Director of Research works in close consultation with seven research committees, has been appointed by the Council to survey the field of research in relation to glass and the glass industry. The terms of reference of these committees are:

1. Chemical and physical properties of glass. (At all temperatures.)
2. Fuels, refractories, furnaces.
3. Glass-making materials, glass-founding, temperature measurement and control; annealing and finishing other than decorative and marking operations.
4. Glassware-forming operations—hand and mechanical; glassware-making machinery.
5. Lamp-working.
6. Design, layout, and equipment of glass factories.
7. Glass decorative and marking operations.

The program of research covers a wide range of subjects, including investigations into the following problems:

1. The dependence of fusibility, range of viscosity, color transparency, brilliancy, refractivity, heat conductivity, expansibility, electrical conductivity, tensile and crushing strength, hardness, brittleness, elasticity, working properties in the blow-pipe flame, resistance to chemical action, and devitrification upon the chemical composition of the glass.
2. The examination and treatment of clays and bricks, the composition and methods of manufacture of refractory materials, the firing of pots, and investigations in regard to refractory materials.
3. The design, construction and operation of furnaces, tanks, pot arches, leers, kilns, glory-holes, etc.
4. The relative value and efficiency of coal, coke, oils, tar, and other combustible mixtures, and gas-producers for various types of furnaces and leers, and the investigation of electrical methods of heating.
5. The most suitable raw materials by means of which to introduce certain chemical elements in the best and most economical forms.
6. Methods of batch mixing.
7. Measurement and control of temperature during founding, chemical and physical changes during founding, determination of most rates of charging and founding different types of glass, effect of furnace gases upon the various types of glass during founding; methods of aiding the fining process.
8. Examination and improvement of the methods and conditions under which molten glass can be conveyed to the forming apparatus; molds and their treatment; mechanical processes of forming glass.
9. Investigation of annealing temperatures, rates of annealing, effect of annealing on physical and chemical properties; methods of detecting and measuring strain.
10. Cracking-off, grinding, etching, enameling, decorating, graduating and marking, lamp-working machinery, and other mechanical processes of finishing.
11. Ventilation of works.
12. Efficiency and health of operators as related to industrial operations.

Apart from the general problem of the industry, members of the Association may, on terms to be decided by the Council, have special information given to them by the Director or staff of the Association, or may have special investigations or researches made for them.

In March, 1920, the Association secured the lease of 50 Bedford Square, W. C. 1 and these premises have been equipped as offices and laboratories, in which research investigators are carrying out intra-mural investigations.

It has been the policy of the Association so far as possible to utilize existing facilities in scientific institutions and in accordance with this policy the National Physical Laboratory at Teddington is proceeding with fundamental researches on behalf of the Association.

Investigations have also been carried out at the Department of Glass Technology, University of Sheffield on behalf of the Association and extensive investigations on problems of founding and forming will be carried out by the Association at the plant of the Department of Glass Technology, Sheffield.

In conjunction with the British Refractories Research Association extensive researches into the fundamental principles underlying the manufacture of refractories for the glass industry and their industrial application are being carried out.

The Association is also coöperating with the Industrial Fatigue Research Board in conducting research investigations into the psychological and physiological problems affecting organization and productive operations of the industry.

Apart from work undertaken by associations and scientific institutions and at factories of members on behalf of the Association, arrangements have been made for scientists, other than those on the staff of the Association, who have specialized in certain branches of scientific investigation as applied to this industry, to undertake researches.

A vast amount of work lies before the Association, and, while realizing the limitations of universities in their relation to industrial research and appreciating their services to industry in furnishing both ideas and trained investigators, the Council is, in its endeavors to solve such of those problems of the glass industry as lend themselves to investigations along academic lines, anxious for the close coöperation of those universities and scientific institutions having equipment and facilities available, and it is believed that as its work progresses the Association will become the center of scientific and industrial research into problems of the glass industry for the Empire.

50 BEDFORD SQUARE
LONDON, W. C. 1

BRITISH SCIENTIFIC INSTRUMENT RESEARCH ASSOCIATION

By J. W. WILLIAMSON

The British Scientific Instrument Research Association is one of the earliest research associations formed under the scheme of the Committee of Privy Council for the promotion of scientific and industrial research. It was founded, as is stated in the third annual report of that Committee, "through the efforts of the optical industry, guided by the whole-hearted energy and zeal of Mr. Conrad Beck, the President of the British Optical Instrument Manufacturers' Association." The Association was incorporated on the 30th of May, 1918, and was established on lines broad enough to include all scientific instrument makers, and also, in view of the intimate relationship between optical glass and optical instruments, the manufacturers of optical glass. In May, 1919, a group of firms representative of the electrical scientific instrument, electro-medical and X-ray industries joined the Association, which may now claim to be, what the above named report of the Committee of Privy Council stated in August, 1918. It had every pros-

pect of becoming the representative industrial body dealing with the application of science to the manufacture of scientific instruments. The Association was fortunate in securing from the outset as its Director of Research Sir Herbert Jackson, K.B.E., R.F.S., formerly Daniell Professor of Chemistry, now Emeritus Professor at the University of London, King's College. Mr. J. W. Williamson was appointed Secretary of the Association and, later, Mr. H. Moore was appointed Assistant Director of Research with especial reference to the electrical and X-ray researches of the Association.

The first task of the newly formed Association was to secure suitable premises for offices and research laboratories and in November, 1918, the remaining term of the lease of 26 Russell Square, was purchased and the Association entered into possession on Armistice Day, November 11, 1918. Steps were immediately taken to effect the necessary structural alterations and to equip the premises with laboratories and secretarial offices and the Association has now a relatively well equipped research institute, with a scientific staff of six research workers, all university graduates experienced in research, in addition to the Director of Research and the Assistant Director of Research.

The Chairman of the Association is Mr. A. A. Campbell Swinton, F.R.S., whose high scientific attainments and wide experience have been and will be of great benefit to the Association.

The Council of the Association consists of fifteen elected members, five co-opted members and five members appointed by the Department of Scientific and Industrial Research. The addition to the elected members of Council of these Department representatives and co-opted members has been of great service to the Association in enabling the Council to view from a wide angle and to a far horizon the varied problems presented to it, without impairing the predominant interest of the members representing the industry or modifying the necessary bias of the Association's activities towards practical results.

The main and immediate functions of the Association, the Council have agreed, are

(a) To prosecute research into the questions of pure and applied science arising out of the urgent needs of the scientific instrument industry;

(b) To take long views and to investigate those questions, whether of pure or applied science, upon which the future of the industry may be conceived largely to depend;

(c) To investigate systematically and continuously the field of application of scientific instruments.

In considering how far the Association has followed out these guiding principles the research work of the Association during the past four years may be classified conveniently under three heads: (1) Fundamental researches; (2) researches on urgent problems of immediate application to

the industry; (3) researches and investigations to solve technical difficulties or to elucidate theoretical questions arising from time to time in the workshops of members of the Association.

It must be remembered that the first year of the Association was necessarily devoted mainly to organization; to the survey of the field of research and the mapping out of the researches; to the acquirement of premises and their equipment with laboratories; and to the engagement of a Research Staff.

I. Fundamental Researches

Among the researches of a fundamental character that have been initiated by the Association, the following are selected as likely to be of interest to the members of the AMERICAN CERAMIC SOCIETY:

1. **Abrasives and Polishing Powders.**—Although these researches have produced results of immediate practical benefit to the industry, as will be shown later, they have involved thorough investigation of the fundamental scientific principles involved in the preparation of materials for the abrasion and polishing of solid surfaces, and they have established principles which must be the foundation of future practice.

2. **Durability of Optical Glasses.**—A prolonged research on methods of testing the durability of optical glasses and of determining the causes which give rise to deleterious changes in certain types of glass has involved much research of purely scientific character into the fundamental relations between chemical composition and physical properties. Although the report on this research, which has been published for general circulation, gives a general account and estimate of the durability of various types of glasses, which will prove of value to the industry, it is, perhaps, especially for its contribution to the knowledge of the behavior of various types of optical glasses under varying conditions that this prolonged research is to be valued. Further investigations in this field are being undertaken.

3. **New Types of Optical Glasses, Neutral Glasses and Colored Glasses.**—The work that has been done on new types of optical glasses, on neutral glasses and on colored glasses, apart from those results obtained which are or may be of immediate practical value, is mainly of a fundamental character, involving research into the relations of chemical composition to optical properties and into the chemical conditions and physical states of aggregation of coloring materials in glasses correlated with the composition of the glasses.

II. Researches on Urgent Problems of Immediate Application to the Industry

Among the researches which have already produced results immediately applicable and of economic benefit to the industry, the following may be mentioned by way of illustration.

As the outcome of the researches on abrasives and polishing powders, products have been prepared, one of which, known as "Sira" rouge, has been manufactured on a large scale and has been for nearly two years in regular use in the workshops of optical members of the Association; the other, to be known as "Sira" abrasive, is now in course of large-scale manufacture for the Association and is being regularly supplied to members.

The "Sira" rouge has been found to be superior to pre-existing rouges and polishing powders for the polishing of high-grade lenses and prisms. Those members of the Association now familiar with its use claim that it takes less than the time previously required for comparable polishing; owing to its purity and uniformity it is less liable than any other known polishing powder to cause streaks; and it gives a finer finish. For the production of the highest class of work it is now used exclusively by the members referred to.

The "Sira" abrasive has now been thoroughly tried out, under industrial conditions, in the workshops of several members of the Association. Here it may be briefly stated that by its use the time of grinding is reduced by two-thirds, with the added advantage of eliminating hand work and the need for grading the abrasives; and the time of polishing surfaces ground with this abrasive is not more, and on the average is less, than two-thirds of the time required to polish surfaces ground in the usual way. It seems, moreover, to have shown promising results in large-scale experiments by members of industries other than the optical and scientific instrument industry. Arrangements are being made for its regular manufacture and supply not only to members of the Association, but to others who employ abrasives in their industrial processes.

We have given above merely a few examples of researches, fundamental and of immediate application, on subjects, or cognate to subjects, in which members of the AMERICAN CERAMIC SOCIETY are interested. The Association has prosecuted and brought to fruition other researches, including electrical and X-ray researches, which are less suitable for reference in the present article.

III. Researches and Investigations to Solve Technical Difficulties or to Elucidate Theoretical Questions Arising in the Workshops of Members of the Association

The work done under this head has been of the most varied and diverse character, and is increasing as the members of the Association realize progressively the help that the Association can give them in these directions. The problems dealt with include the improvement or modification of materials already in use, the finding of substitutes for existing materials, the use of new materials, and the explanation and solution of technical difficulties in manufacture.

The work that has been done under heads II and III above has been not only of direct benefit to the members, but it has kept the Director of Research and the Research Staff in close touch with the practical needs and difficulties of the industry. The result has been to create, slowly but surely, a research institute of a valuable and, to a great extent, a new type, because of the intimate special knowledge which the Association has acquired of the particular needs and working conditions of the industry. It is stated in the last annual report of the Association that in reviewing the work done during the last four years the Council of the Association recognize, as they are confident the members also recognize, that the Association is a concrete example of the benefits to be obtained from organized, coöperative research, in which the scientific worker, the manufacturer and the user each plays his appropriate and coöordinated part.

It may be well to point out that, besides the specific researches included in the program of research, the Association in its character as the scientific center of the industry, is called upon from time to time to assist the industry by contributing from a scientific standpoint suggestions and criticisms to the appropriate Government and other quarters on such matters as the supplies of raw materials and the manufacture in this country of products essential to the development of the British scientific instrument industry. Much work in this direction has already been done. Moreover, users of scientific instruments have already brought to the notice of the Association, and, as the Association becomes better known, will doubtless tend increasingly to bring to its notice, their specific needs. In this way the Association will perform a useful scientific liaison office between the users and the manufacturers. Already, by means of conferences and otherwise, the Association has enabled the manufacturing members to become better acquainted with the scientific needs of the users, and the users to appreciate the limitations imposed on the manufacturers by design, material or other conditions.

In the task of industrial reconstruction after a devastating war which the British scientific instrument and optical glass industries, in common with other British industries, have now to face and accomplish, their most potent means must be the extension of scientific research to the varied problems of the industries. In this work the coöperative research of the Association and the particular research of the individual firms are essential and complementary. The work of the Association not only does not supersede but emphasizes the need for, and assists, the scientific research undertaken by individual firms. In the same way the pure science research of the universities and kindred institutions is essential and complementary to all research carried out by the research associations or by industrial firms. The universities and their like are the great sources of pure scientific research and to them we look for that fundamental work which

probably in many cases not of immediate applicability to industry is bound to be the foundation of future guiding principles. Nowhere is this more fully recognized than in the British Scientific Instrument Research Association. Its work is also largely purely scientific but to fulfil its purpose of immediate utility to its relevant industries it necessarily cannot always follow through to completion the numerous lines of investigation which arise out of the problems studied.

CLIFF BANK HOUSE
UPPER CLIFF BANK
STOKE-ON-TRENT, ENGLAND

THE PROGRESS OF TECHNICAL CERAMIC SCIENCE IN GERMANY SINCE THE DEATH OF HERMAN SEGER (1893)

BY K. H. ENDELL AND R. RIEKE

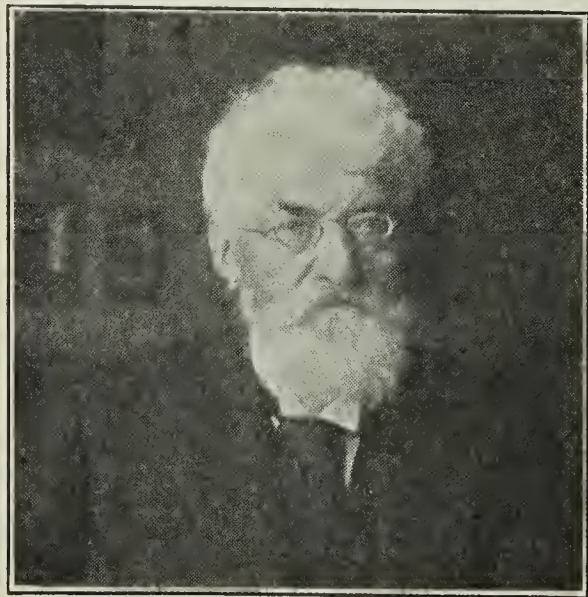
(Translated from the German by E. E. Pressler)

I. The Period from the Death of Herman Seger to the Founding of the German Ceramic Society

Following the death of the early master Herman Seger, the founder of the ceramic science in Germany, the development of ceramic science in Germany proceeded along diversified lines. Some investigations were conducted upon the problems of the domestic porcelain manufacture in the testing station in Charlottenburg (Charlottenburger Versuchsanstalt). These were extended to include all branches of ceramics.

In the testing station, the following men have been active at various times: E. Cramer, H. Hecht, M. Marquardt, E. Berdel, M. Simonis, R. Rieke, K. Endell, W. Steger.

Many investigations for the growing industry were made in the laboratory for Tonindustrie (Tonindustrie-Laboratorium), which had been es-



DR. HEINECKE

tablished by Seger. The society, "Kalk-Ton-Zement Verein," which was then in a state of thriving growth, gathered in its annual meetings all scientists in the field of ceramics. We find in its annual reports, which are printed by the publishers of *Tonindustrie*, contributions of the leading ceramic men of that time. The Society, "Verein Deutscher Fabriken feuerfester Produkte," did meritorious work as a scientific society from the beginning of the new century up to the outbreak of the War. Work was done upon various problems relating to the refractory industry and

its commercial phases. The official medium was *Tonindustrie*, while more

elaborate works were given out elsewhere. In 1910 and 1911, Professor F. Hofmann worked in the technical institute, "Physikalisch-technische Reichsanstalt," in Charlottenburg, upon the fusion point of Seger cones under laboratory and industrial conditions. These and other investigations are found in the annually published proceedings of the Society, published by *Tonindustrie*, Berlin.

In the field of glassware, Mylius worked out in the Institute "Physikalisch-technische Reichsanstalt" a method (Glas-Eosinprobe), of determining the resistance of glasses to chemical action.

Independent development was shown by the Society "Verein Deutsche Portlandzementfabrikanten," which later incorporated with it "Verein der Eisenportlandzement- und Hochofenzementwerke." The Society was identified in the outstanding personality of the noted cement investigator, Wilhelm Michaelissen. Through scientific and practical work, and leading suggestions by the foremost scientists, various problems of general and special interest within the scope of the Society were solved. The laboratory is in Karlshorst, and has been directed since 1910 by the able Dr. Framm.

The producers of cement using refractory slags, through the Society, "Eisenportlandzement- und Hochofenzement-Verein," established a new institution for slag investigation (Schlackenforschungs-institut) in Düsseldorf in December, 1922. The Institute is under the direction of Dr. A. Guttman and Dr. Richard Grün.

Investigations for optical glasses and glasses for technical glasswares were made almost exclusively by the firms Schott and Genossen in Jena, and the Sendlinger Optical Glass Works in Berlin-Zehlendorf.

II. German Ceramic Society

On June 13, 1913, the Society of the Associated Ceramic Works in Germany (Verband Keramischer Gewerke in Deutschland) established a special division, designated as the "technical scientific division" for the two-fold purpose: (1) of furthering the technical and scientific phases of ceramics, and (2) harmonizing the efforts of theoretical and practical workers of ceramics. This division held annual meetings, before which papers were read. These were published as annual reports in Coburg, under the designation: "Berichte der technisch-wissenschaftlichen Abteilung des Verbandes Keramischer Gewerke in Deutschland" (Vol. 1, 1913; Vol. 2, 1914; Vol. 3, 1917; Vol. 4, 1918, Vol. 5, 1919).

In a meeting held September 29, 1919, this division was reorganized. Its field was extended to include all ceramic science, and accordingly it soon thereafter assumed the name "Deutsche Keramische Gesellschaft." Since the middle of 1920, the German Ceramic Society has issued its own bi-monthly reports. The Society is supervised by eleven trustees, who are

representatives of the technical ceramic sciences. There is also a working committee consisting of eleven representatives of the Society of the Associated Ceramic Works and other technical ceramic societies, and twelve representatives of ceramic science connected with universities, trade schools, and ceramic periodicals. For the consideration of special problems, committees have been named (1) for problems of firing; (2) for problems relating to lead; and (3) for protection in industrial rights.

In 1920, a drying establishment and an installation of ceramic machinery and equipment was secured for the benefit of information to members.

The direction of the scientific work of the German Ceramic Society rests with R. Rieke, who is also director of the chemical-technical experiment station of the State Porcelain Factory (Staatliche Porzellan-Manufaktur), and Professor of the Technical University. The Society renders excellent service in furthering scientific ceramic work, in giving technical assistance to the general ceramic industry, and in promoting ceramic instruction.

The Society is in process of substantial growth, and includes as members most firms in the ceramic industry in Germany. The present membership is about 1400. The business address is Berlin, W. 30, Victoria Luise Platz 11.

In the summer of 1922 the German Society of Glass Technology was organized. This Society aims to serve the glass industries as the ceramic society serves the clay industries.

III. Biographical Notes on the Present Leaders in Technical Ceramic Science in Germany

Biographical notes are being given on the following men: E. Berdel, E. Cramer, K. Endell, H. Hecht, A. Heinecke, G. Keppeler, J. Koerner, F. Kraze, W. Pukall, R. Rieke, W. Stegers.



E. BERDEL

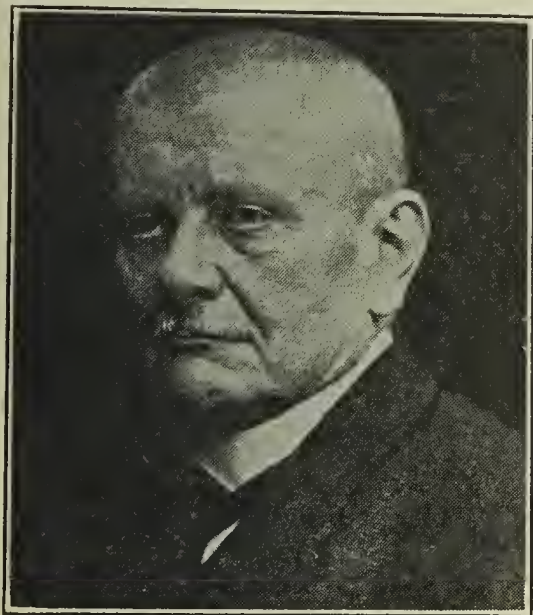
Eduard Berdel

E. Berdel was born Feb. 1878 in Zweibrücken. He completed the course of the local humanistic gymnasium in 1896. Studied chemistry and natural science in the Universities of Munich and Erlangen. By virtue of his dissertation "Beitrag zur Kenntnis der Legierungen" the title of Doctor of Philosophy was conferred upon him by the University of Erlangen in 1901. In 1899, Dr. Berdel became assistant in the chemical laboratory of the University of Erlangen. In 1902, he was made assistant in the chemico-technical experiment station of the Royal Porcelain Works (Königliche Porzellan-Manufaktur) in Berlin, where he remained until 1905 when he was made

instructor in the Royal (now State) Ceramic Trade School in Hoehr. Since 1913 Dr. Berdel has been director of the State Ceramic School in Hoehr, near Coblenz. He has written many articles for the technical press, especially for *Sprechsaal*.

Eduard Cramer

E. Cramer was born in 1859 at Bochum, Germany. He completed the work of the Public Trade School in Bochum and attended the Technical Universities of Hannover and Berlin from 1877 until 1881. During this time he was assistant chemist in chemical technology. In 1883–1886 he was assistant chemist to Seger in the experiment station of the Royal Porcelain Works in Berlin. In March 1886 Mr. Cramer entered the chemical laboratory for *Tonindustrie* and *Tonindustrie-Zeitung* of Seger and Aron, taking the place of Dr. Aron, and later became partner.



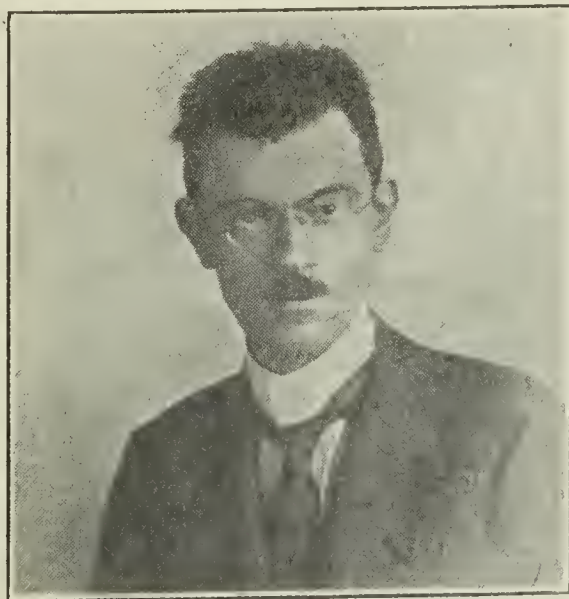
E. CRAMER

Mr. Cramer's varied services for the German building material industry have been recognized by the leading trade associations by election to honorary membership. He is honorary member of "Bund deutscher Fabriken feuerfester Erzeugnisse," "Verein Deutscher Kalkwerke" and "Reichsverein der Kalksandsteinfabriken." He is a trustee of a number of other societies, and advisory member of several scientific committees. The ceramic hand-book "Handbuch der Tonwarenindustrie von Bruno Kerl" revised jointly by Cramer and Hecht is recognized as a

standard work. Because of his extensive fundamental knowledge, Cramer's activities and knowledge of materials cover a very wide scope.

Kurd H. Endell

Kurd H. Endell was born in Stade in 1887. He studied in Lausanne in 1905, at Grenoble in 1906 and at the University of Berlin 1907–1910 in the latter year taking his Ph.D. degree. In this same year he became assistant in the experiment station of the State Porcelain Factory, and in 1911 was made assistant in the Institute of Mineralogy at the University of Berlin. Since 1913 Dr. Endell has been instructor of technical building science in the Charlottenburg Technical University. In 1919 he was appointed resident scholar for mineral-chemistry and its industrial application. During 1917–1918 he was assistant in scientific research for the Optical Glass Firm of G. P. Goerz of Berlin and the Sendlinger Optical Works in Berlin-Zehlendorf. From 1918 until 1920 he was assistant in scientific research for "Deutsche Portland Zement-verein." He was also publisher of *Zement* from 1919 to 1921. Dr. Endell is a member of the following technical societies: "Vereindeutscher Eisenhüttenleute," "Metallhütten-und Bergleute," "Deutscher Chemiker," German Ceramic Society, English Ceramic Society, Society of Glass Technology, AMERICAN CERAMIC SOCIETY, and American Society for Testing Materials.

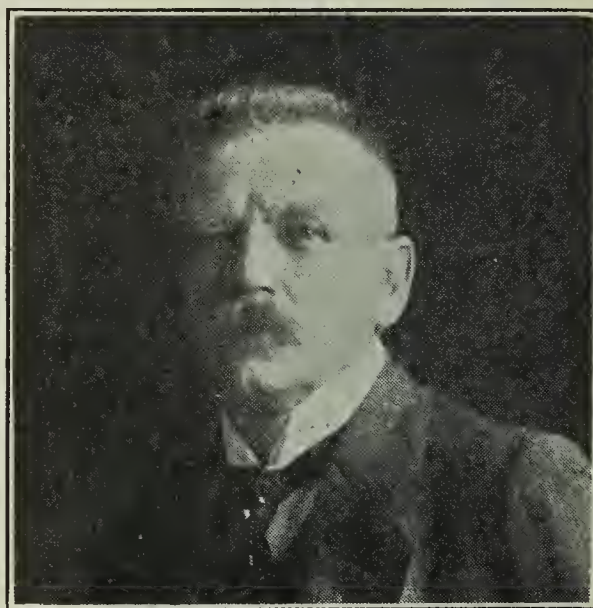


K. H. ENDELL

Extensive travels for industrial survey were made in 1908, 1911, and 1921 in Europe, and in 1922 in United States and Canada. Dr. Endell has written many articles for both German and American publications of technical value to ceramists.

Herman Hecht

Herman Hecht was born in NeuhoF near Stralsund in 1860. He was a student in chemistry and natural science in Berlin, graduating in 1887. From 1886 until 1897 he was assistant and then head of the Chemical Technical Experiment Station of the Royal Porcelain Works in Berlin. In 1897 he became connected with the Charlottenburg Technical University, as instructor in ceramics. From 1897 until 1900 he was a member of the German Patent Office, and in 1898 was elected to State Council. Since 1894 he has been joint owner of the chemical laboratory for *Tonindustrie* and associate editor of that publication. Since 1909 he has also been Editor of *Keramische Rundschau* and since 1888, has contributed many writings on technical subjects.



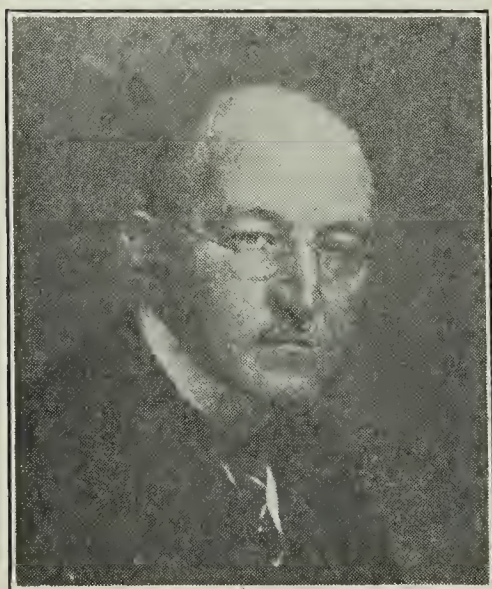
H. HECHT

Albert Heinecke

Albert Heinecke was born at Tiedenwiese in Hannover in 1854. He studied chemistry in Leipzig and Berlin, and in 1879 became assistant in the Royal Porcelain Works, where he advanced from the position of industrial chemist to manufacturing director. Under his direction the factory made marked progress in technical and artistic developments. Dr. Heinecke retired in 1914 after thirty-five years of active work in this factory.

Dr. Heinecke has been instrumental in the development of the ceramic industry through both his written and spoken contributions. In recognition of his services in elevating the science of ceramics in Germany, the German Ceramic Society elected him to honorary membership, and, within recent years, the Technical University of Berlin conferred upon him the title of Doctor of Engineering.

Gustav Keppeler



GUSTAV KEPPELER

Gustav Keppeler was born in Heilbronn in 1876. He studied in Stuttgart and Heidelberg, and was assistant in Karlsruhe and Darmstadt for several years and later instructor. He was professor in the Technical University of Hannover, giving technical instruction in the peat, clay and glass industries. Mr. Keppeler studied problems of fuel technology and general inorganic chemistry, and, through investigations in clay casting conducted jointly with Spangenburg, became interested in the technical ceramic science. The investigation led to a valuable technical application for the manufacture of fire clay wares of heavy construction, such as bath tubs, and also applicable to the grog industry (German Patent 201,987).

After a short connection with the technical experiment station of the Royal Porcelain Works in Berlin, Keppeler in 1908 became interested in instruction and research in ceramics, in the newly established institute in Hannover. Here he has since rendered service in ceramic lines both through instruction and investigation. His chief object of investigation has been the subject of the plasticity of clays. Processes of casting were also developed. Keppeler also became known through his service in assisting in the publication of Dralle's "Die Glasfabrication." The primary object of his investigations relative to the publication of this book was to establish the relation of the composition of glasses and their resistance to chemical action.

After the death of Robert Dralle in 1918, Keppeler undertook the compilation of a second edition of the collected works of Dralle. Within the course of the next year, a thoroughly revised second edition will be forthcoming. Mr. Keppeler, as Editor, would appreciate any suggestions from American sources upon subject matter to be included, so that he might more fully consider American industrial requirements and contributions.

Joseph Koerner

Joseph Koerner was born in Alsace in 1872. He studied chemistry in the Universities of Strassburg, Leipzig and Erlangen, receiving the degree of Ph.D. from the last named University. Koerner was assistant in chemistry in the University of Erlangen for two years and in 1901 entered the Experiment Station of the Royal Porcelain Works of Berlin. In 1905 he assumed the direction of the Imperial Majolica Works at Cadinen. Since 1907 he has been Editor of *Sprechsaal*.

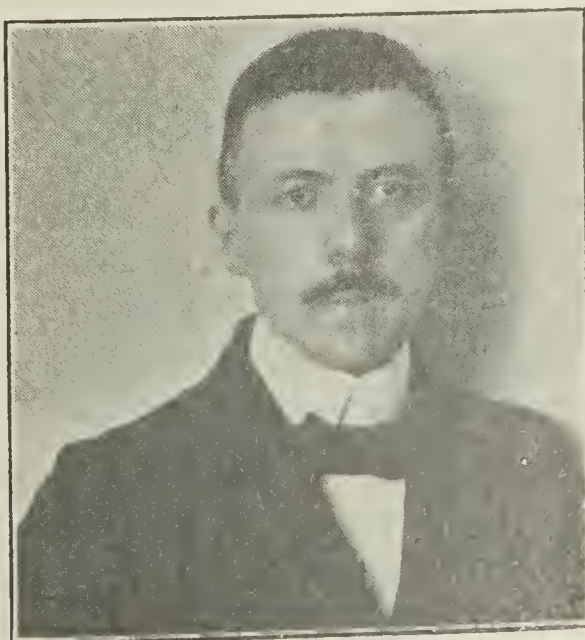


J. KOERNER

der natürlichen Bausteine auf ihre Wetterbeständigkeit." During 1903-1904 he was industrial engineer for the enameling works, "Silesia," and certain iron works in Upper Silesia. In 1904 he was appointed instructor and head of the Division of Silica Technical Instruction in the municipal "Friedrichs-Polytechnikum" in Cöthen-Anhalt. Here he gave instruction in ceramics, refractory products, brick manufacturing, technology of cement, mortar and artificial stone manufacturing, glass manufacturing, and iron enameling. Besides the training of engineers in the above named branches of the silica industry, Prof. Kraze also served as technical advisor in this industry. He interests himself particularly with problems of iron enameling. He is consulting advisor for The Society of German Enamel Works.

Fritz Kraze

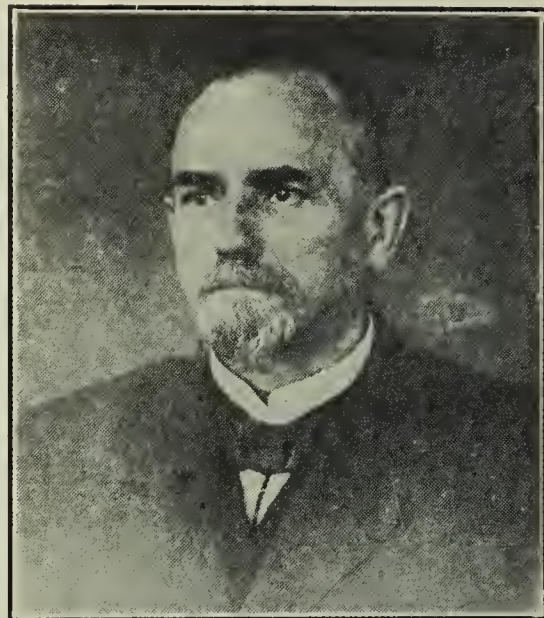
Fritz Kraze was born in 1878 in Silesia. He attended the Technical University in Berlin and became assistant in Mineralogic-Geology in this school. He was also co-worker with Councillor Dr. Hirschwald in his work "Die Prüfung



FRITZ KRAZE

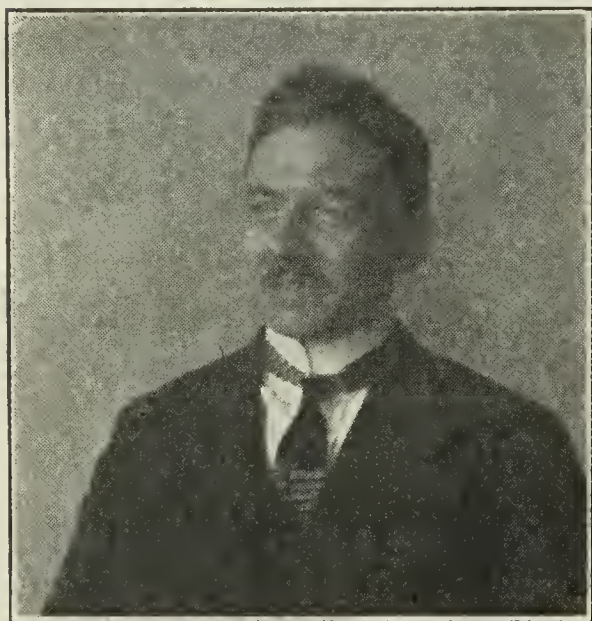
Wilhelm Pukall

Wilhelm Pukall was born in West Prussia in 1860. He completed his studies in Berlin, receiving the degree of Ph.D. For ten years, he was industrial chemist in the Royal Porcelain Works of Berlin-Charlottenburg. He then assumed the direction of the newly established ceramic trade school in Bunzlau in Silesia, which position he still holds. To this institute has been delegated the problem of training students for the theoretical and practical aspects of the ceramic industry. In November, 1922, the State Ceramic School in Bunzlau celebrated the twenty-fifth anniversary of its founding, and upon this occasion the Technical University of Breslau conferred upon Pukall the title of Doctor of Engineering. He is an honorary member of the



WILHELM PUKALL

German Ceramic Society. Dr. Pukall has written numerous technical articles, and in 1907 published a text-book on Ceramic Calculations.



REINHOLD RIEKE

Reinhold Rieke

Reinhold Rieke was born in Riga, Russia, in 1881. He studied chemistry in Freiburg and Leipzig. He then became assistant in the department of technology of the University of Freiburg, completing his studies there. In 1905, Dr. Rieke became chemist of the technical-chemical experiment station of the Royal Porcelain Works of Berlin-Charlottenburg. During 1908 and 1909 he was technical assistant in this factory. In 1919 he became instructor in the Technical University of Charlottenburg, and in 1921 was

appointed instructor of ceramics. He also received the appointment of head of the experiment station in the Royal Porcelain Works. In 1919 he was assigned the direction of scientific and literary work of the German Ceramic Society, and in 1920, he established the "Berichte der Deutschen Keramischen Gesellschaft," which he still edits. In 1922 he became Assistant Professor in the Technical University of Charlottenburg. Since 1905, Dr. Rieke has published many papers on ceramic subjects.

Walter F. Steger

W. F. Steger was born in Silesia in 1889. He studied chemistry in the Universities of Berlin and Jena, and received his Ph.D. degree in 1913. He is now chemist of the technical-chemical experiment



WALTER F. STEGER

station of the Royal Porcelain Works in Berlin, and is assistant to Dr. Rieke. Here he has conducted investigations upon porcelain glazes, stoneware glazes, and fireproof building materials. The results of his investigations have been published in various German publications. In January, 1923, he becomes a member of the Government Patent Office in Berlin, connected with the Division of Ceramic Patents.

IV. Instruction in Ceramic Science in Germany

The institutions giving instruction in ceramic science in Germany may be divided into four groups.

The first group includes trade instruction shops in industrial continuation schools, and departments in art and industrial-art schools. The training in these is limited to purely handicraft or artistic lines. In only a few schools of this class is technical-chemical instruction given.

The second group includes the distinctly technical ceramic schools, and schools for instruction in brick manufacture. Such schools are found in Hoehr near Coblenz, in Bunzlau, Selb, and Landshup. Of these the first two named are the largest and best known. These schools treat of all branches of ceramic science, except the one in Selb, which restricts its work to the porcelain industry.

A third group consists of institutions giving instruction of a more purely technical character. Of these the most important is the Friedrichs-Polytechnic Institute in Coethen.

A fourth group is made up of technical universities. In most of these, the science of ceramics is given only slight consideration. In some, only general lectures in ceramics are given, and only in Charlottenburg, Breslau, and Hannover are provisions for practical training found. The best advantages are offered by the Charlottenburg Technical University, where students of ceramics have access to the laboratory and equipment of the technical ceramic experiment station of the State Porcelain Factory in Berlin.

V. Investigation and Experiment Stations

The institutions named below conduct systematic investigations of problems in ceramic science.

(1) Physikalisch-technische Reichsanstalt. The work of determining the fusion point of Seger cones was done by F. Hofmann at this station, and in 1912 Dr. Hofmann, K. Endell, and Dr. Rieke made the first satisfactory determination of the melting point of cristobalite in Germany. This was done at the same time, but independently, by C. N. Fenner of Washington, D. C.

(2) Staatliches Material-Prüfungsamt. This Institution in Berlin-Dahlen was commissioned by State authorities to establish norms of re-

fractory rocks. Important investigations of the heat conductivity of refractory rocks were made here by E. Heyn and R. Bauer.

(3) Deutsche Gesellschaft für Materialprüfung der Technik. In 1920, this Society authorized a committee to work on simplifying methods of testing porcelains, which devoted itself particularly to methods of mechanical testing.

(4) Tonindustrie-Laboratorium. This Institution keeps in close touch with private industry. Since Seger's death, it has been directed by E. Cramer and H. Hecht.

(5) Geologische-Landesanstalt. This Institution occasionally works on ceramic problems.

VI. Periodic Ceramic Literature

Of the technical periodicals now published in Germany, those of chief interest to the members of the AMERICAN CERAMIC SOCIETY are the following:

Keramos: periodical for ceramic art, published since 1922 in Munich.

Die Kachel- und Töpferkunst: published since 1922 in Berlin.

Zement: Periodical of cement production and utilization published since 1912 in Charlottenburg.

Die Glashütte: published in Dresden.

Die Glasindustrie: industrial publication of Spaeth and Linde in Berlin.

Many articles bearing upon ceramic science also appear in the published annual proceedings of "Verein Deutscher Portland-Zementfabrikanten," "Deutscher Kalkverein" and "Deutscher Gipsverein."

Papers bearing upon refractory materials are often published in *Stahl und Eisen*, and also in reports of "Verein Deutscher Eisenhüttenleute" in Düsseldorf, and *Zeitschrift für angewandte Chemie* in Leipzig.

The rising technical science in Germany has successfully entered industrial fields. Many firms have established great laboratories, such as porcelain factories for physical and chemical testing of chemical and electrical porcelains; optical glass manufacturers for the particular requirements of optical glasses; and manufacturers of refractory materials for tests of refractory behavior. Great industrial laboratories devote themselves exclusively to the development of new ceramic colors, glazes and enamels.

THE CERAMIC INDUSTRIES OF FRANCE SINCE THE END OF THE 19TH CENTURY

BY A. A. GRANGER¹

(Translated from the French by F. G. Jackson)

It can be said that the ceramic industry is represented in France in all its branches; bricks, tile, paving brick and terra cotta; refractories; earthenware and china; stoneware; hard and soft porcelain.

Brick, Tile and Terra Cotta

There are in France a good many brick plants of very varying importance. They may be divided into two types. The first, still using the old processes, treat slightly argillaceous earth which they mould sometimes by hand and sometimes in hand presses, and burn them in cone kilns. Such small hand brick plants are scattered throughout the country. They do only a local business and employ but few people. Their number tends to diminish progressively.

Contrasted to these ancient plants there are modern plants capable of making beautiful bricks by mechanical processes. They generally use the mud process. The dry press process is exceptional. The brick industry is much occupied with the question of driers and cannot decide what type is better for a



GABRIEL FAUGERON

given clay. The bricks are burned, in the majority of cases in kilns of the Hofmann type in most part using coal, and a few using gas. Some of the brick companies make other products such as terra cotta.

What I have said of bricks may be repeated about tiles. There are still in France in the country, small hand tile factories and there are mechanical tile factories. The form of tiles made in the country is varied. The mechanical factories principally make rectangular tiles. The mechanical tile is made by pressing a cake of clay conveyed on a belt to the press. This may be a soft or a hard cake. In the first case they are put in plaster molds and in the second in metal molds. The two processes have their advantages and their inconveniences. They are baked in continuous kilns as are the bricks. The Hofmann kiln can be used for bricks and tile at the same time. The kiln is set with the bricks arranged to protect the tile from the coal dust which would make spots.

¹ Chief of the Testing Laboratories and Professor of Ceramic Technology at the Manufacture National of Sèvres.

Coping bricks are made by spinning and repressing.

There are terra cotta factories throughout France but particularly in certain centers. The North, the Departments of Saone and Loire, and the vicinity of Marseilles, are the greatest producers. It is difficult on account of the disorder brought on by the War to give statistics of these factories but without great error one can say that the terra cotta industry employs from 4000 to 4500 men spread over 700 factories.

Refractories

Refractory clay products are made all over France. The bricks are made by machine. The dry press process is very seldom practiced. Special shapes are moulded.

In the fabrication of gas retorts they have introduced mechanical methods, but this method is not used widely to my knowledge.

A certain number of factories use continuous kilns but one still finds intermittent kilns in this industry.

The making of special refractories has not had a serious development. France does not have enough magnesia to permit her to develop the manufacture of magnesia bricks. Nor can she work, except on a small scale, with magnesia from eastern sources. The chrome brick manufacturing is not a flourishing industry. The silica brick alone has been the object of an interesting research especially during the War in order to assure of its production. It does not seem up to the present that one can arrive at a concise determination of the characteristics of the quartz in silica bricks.

Artificial corundum has been used in several refractories. As the factories making refractories are not always strictly limited to refractories it is difficult to give an estimate of the number of plants and persons employed.

Pottery

Pottery is made in France in transparent enamel or opaque enamel and china and is used especially as kitchen utensils and household articles (pots and pans, utensils for baking and mash bowls, etc.). This industry has not made any noticeable progress for many years. It extends over all of France and still follows the old methods. In certain sections one may see the enamel prepared with Galena or lead sulfide as the principal ingredient. Besides the enamel pottery one must cite the colored clay potteries.

The opaque enamel industry occupies at present a very precarious position. This type of pottery has not been able to compete with china, in part because of its technical faults and in part because of the incapacity of the factories which have made no improvements in one hundred years.

They still make some Dutch tile stoves and some hearth brick both of which are becoming more difficult to sell on account of improved heating methods. A very small number of factories make *bibelots*. The importance of their production is small in comparison to those making china.

The china industry is much more important than the pottery industry. From statistics taken sometime ago it is certain there are least 12,000 workmen. The largest plants are grouped principally in the region of the department of the North (Saint Amand, Orchies, Onnaing in the East (Lunéville, Badonvillers, Pexonne, Longwy, Sarreguemines), in the district near Paris (Choisy le Roi) in the boundaries (Montereau) in the center (Digoin). These factories total 300 kilns each of 100 to 150 cubic meters.

The French manufacture of china is not exactly like the English. The raw materials: silica (with a little quartz sand, more or less mica or feldspar), refractory clay, white burning pegmatite, and native kaolin. English clays are used (ball clay) and English kaolins.

The clays are found principally in the basin of the Marne and equally in the region of Charentes. The kaolins used form the central rock (the Collettes, Beauvoir) from Bretagne (Lorient, Plémet, etc.) the kaolins from the Limoges region being reserved for the production of porcelain. Flint is abundant in the most of France and the fusible rocks are also abundant.

In the preparation of the paste one has recourse ordinarily to the wet way that is to say to mix the raw materials in a slip. The Alsing mill is generally used for the grinding.

The work is entirely mechanical. Casting is employed quite largely as it demands no especial training. In some factories it has completely taken the place of jiggering. The tendency is to establish automatic machines for the preparation of the paste and the formation of the ware. The machinery of this has been especially studied by M. Faure of Limoges.

The greatest progress made in the manufacture of china is due to Mr. Faugeron who first succeeded with a continuous glost kiln and then later with a continuous biscuit kiln. From 1899 the glost kiln which he had constructed at Montereau was a success. Before good results were obtained a second kiln was constructed in 1900 and in 1901 for the burning of the biscuit. The Faugeron kiln is a tunnel kiln with a particular arrangement for good gas circulation and consequently even burning. The experiments performed almost at the same time with the continuous circular kilns have not given the same satisfaction and in the china industry of France the Faugeron tunnel kiln is considered to be excellent.

The introduction of glazes without lead dates from about 1904; at least it is at about that date that the factory at Montereau commenced to employ them industrially. This use of glazes without lead, necessitated for

hygienic reasons, is accountable for many colors developing badly. These glazes without lead have a luster less shiny than those with lead.

The expense of engraving being very high there is actually a tendency to development of decoration by air-blast and the impression by a rubber buffer.

I will cite in closing the perfecting of a machine of M. Centore which presses, with the aid of one workman and two boys, from ten to twelve plates a minute or a minimum of 4800 plates a day. The same machine may be used on any sort of shape not too irregular or too exaggerated.

I cannot leave the faience without a word on terra cottas and architectural brick. These products are earthenware since they are enameled and are made by the factory which make both earthenware and china. In France there is a large consumption of Dutch tiles for walls. These tiles are made in some places together with pottery and sometimes in factories producing all branches of ceramics.

Stoneware

The manufacture of stoneware for domestic use is for the greater part still in the hands of little potteries whose work follows the mode of the most primitive potteries. The largest pieces which cannot be turned are often made by modeling. The most important groups are those of Beauvaisis (La Chapelle aux Pots), of Normandy (Noron), of Nièvre (Saint Amanden Puysaie), of Cher (La Borne), etc. There are also some small modern factories such as those of Seurre and Pouilly on the Saone, of Roanne for chemical stoneware and sanitary pottery. The first of these factories belonging to the Société Jacob at Delafon uses Dinz continuous kilns. This operation which to my knowledge is not common has been considered a great improvement since it permits of the burning of large pieces in a continuous furnace.

The stoneware made by the small potteries is composed of simple mixtures of clays burning naturally into stoneware. In the larger factories more is known about the composition of their clays. The burning of French stoneware rarely attains cone 9, and sometimes as low as cone 5. Beside the stoneware potteries there is also an important manufacture of stoneware bricks. Several of the factories work stiff mud which they cut and afterwards press, but generally the production follows the dry press process, using a hydraulic press. The north of France exports a large amount of this product, particularly in polychrome and crusted bricks. The burning is still done in intermittent kilns. Some interesting experiments have been made with the Dressler kiln and permit us to predict that the tunnel kiln will take the place of the intermittent kiln in this industry.

Porcelain

The manufacture of hard porcelain has but little importance in France. The two important centers of manufacture are in Berry (Vierzon) and in Limousin (Limoges). The porcelain industry in these two regions is divided into two industrial groups one of which is the *patiers* who deliver the paste all prepared to the factories, the latter molding, cutting and decorating this paste. The raw materials are in part French, and before the War considerable quantities of English kaolin and Scandinavian feldspar were used. The beds of kaolin cited apropos of china contribute some of the kaolin that is used but there are in the outlying regions, principally in the South, important beds of kaolin, rock and feldspar. In the region of the Pyrénées we also find beds of feldspar and other kaolinite rock deposits. The *patiers* are always established if possible along the rivers in order to utilize hydraulic power. La Société des kaolins et Pâtes Ceramiques of Limousin have a number of well equipped mills. Profiting by the neighboring falls the region around Limousin uses electricity as much as possible.

The progress made in the production of porcelain is important. The machines for forming the ware have been notably improved by M. M. Faure, and by M. Rouchaud who have designed plate machines almost absolutely automatic.

M. Charbonnier very recently has perfected a machine to make the saggers and has also worked out a method of employing pressure in the casting process.

The production of electrical porcelain has resulted in improved presses especially for the production of large pieces. Until the present time the burning of porcelain in continuous kilns has had no great adherents.

Few of the factories make laboratory porcelain. The Manufacture de Bayeux has acquired a certain fame in making divers laboratory articles. M. Frugier of Limoges during the period of hostilities made some interesting pieces. Since the War the number of kilns in use has not changed much at Limoges, but the number of workmen has diminished (about one-third). A recent count placed them at a total of 18,000.

Soft porcelain (bone china) is not made except in a small quantity at Sarreguemines. Soft frit porcelain apart from one or two isolated attempts does not seem to have been crowned with success, and is only made by the Manufacture of Sèvres.

Manufacture of Sèvres

The Manufacture of Sèvres has for its principal product hard porcelain which is made in two forms. (1) The hard porcelain, called old porcelain, and a porcelain with a very aluminous base:

SiO ₂	60.58
Al ₂ O ₃ .Fe ₂ O ₃	31.77
CaO.....	4.00
K ₂ O.Na ₂ O.....	3.15

This burns with cone 13 well down. This porcelain is given a glaze of the type: 8.43 SiO₂, 1.05 Al₂O₃, 0.347 (MgO.CaO), 0.653 (K₂O.Na₂O). This is a hard glaze used particularly for tableware and for decorating under the glaze.

(2) The hard porcelain called new, which is more siliceous, approaches a china type which burns at cone 9.

SiO ₂	69.58
Al ₂ O ₃ .Fe ₂ O ₃	24.45
K ₂ O.Na ₂ O.....	5.34
MgO.CaO.....	0.66

This glaze has the composition as Seger cone 4: 4 SiO₂, 0.5 Al₂O₃, 0.3 K₂O, 0.7 CaO. It is used more especially for decoration and enamels.

The trade has also made stoneware and has created a type of stoneware specially designed for receiving all sorts of colored glazes. The stoneware of Sèvres is composed of

Plastic clay.....	56
Flint clay.....	27
Black fusible mica.....	26

It is burned to cone 9 like the new porcelain.

The manufacture of soft porcelain or soft French porcelain, using a frit had been abandoned by Brongniart in the first years of his administration about forty years ago. This process, difficult and uncertain as to results, had the added disadvantage of being very expensive. It was also out of fashion, hard porcelain being the vogue.

The taking up again of a delicate process, which had been completely abandoned for forty years, presented great difficulties, since the staff had no longer any traditions. Uncertain records left by the men of the eighteenth century made the investigators exert great efforts which did not succeed until about 1900, in time for the Universal Exposition in Paris. The principal difficulty consisted in the use of a frit made from imperfect glass which made the fusible element. They replaced the frit by a hard glass of the sort used by Stas in his work on the determination of atomic weights. The glass replacing the frit is composed of

Silica sand.....	77
Chalk.....	18.40
Saltpeter.....	16.60
Carbonate of soda.....	8.50

This glass is less alkaline than the old Sèvres frit. This is an advantage since it is less altered by the water during the grinding and working of the paste. The Sèvres factory has exhibited a certain number of pieces of following formula. The paste contained:

Silica sand.....	33
Stas glass.....	46
Chalk.....	14
Clay.....	7

and the glaze was composed of 2.5 SiO_2 , $0.46 \text{ Na}_2\text{O}$, 0.54 PbO .

This type has been modified for the introduction of kaolin in place of clay. Work is still going on to improve it. This soft porcelain lends itself to decoration particularly to the application of enamel.

This factory has experimented with the burning of hard porcelain with fuel oil. These tests have given great satisfaction in regard to regularity of burn and ease of control. It would even seem possible with large kilns to realize an economy. In little test kilns the cost is particularly the same, at the present price of fuel oil, as with coal.

Ceramic Research

Ceramic research is now placed under the direction of an organization (l'Institut de la Céramique Française) aided by the workmen's agreement and a budget given by the state, has just entered upon its activities. It is occupied in developing the study of ceramics and aiding the industries by means of a research laboratory.

The study is divided between two schools. The School of Ceramics annexed to the Manufacture of Sèvres passed under its control and is the highest school of ceramics designed to make engineers. The school installed at Vierzon is designed to make foremen.

The regional schools are simply to inform special workmen.

The experimental laboratories created by the Manufacture Nationale de Sèvres enters equally in the fame of the Ceramic Institute. Its installation will make it possible to carry on researches under good conditions and admit workers who wish to study industrial problems. The city of Paris had an École des Beaux Arts applied to industries with a ceramic section.

Publications Concerning Ceramics

Lefevre, *La Céramique du Batiment*, 1897.

Larchevêque, *Fabrication industrielle de la porcelaine*, 1898.

Bourry, *Traité des Industries Céramiques*.

Granger, *La Céramique industrielle*, 1907

Matériaux et Produits réfractaires, 1910.

Pierres et Matériaux artificiels de construction, 1908.

Le Chatelier, *La Silice et les silicates*, 1914.

There are no publications in France especially devoted to ceramics. The two journals which are the organs of the two groups publish the technical articles. *La Céramique* is the organ of the Syndicate des Fabricants de Produits Céramiques de France. *La Céramique et la Verrerie* is the organ of the La Céramique et La Verrerie.

The Society, as an encouragement to these national industries, has published a certain number of memoirs which were gathered together in 1906 in a volume containing such articles as La Ville, geological studies of clays of France; Le Vezard, contribution on clay beds of France; Vogt, on the composition of clays and china porcelains; Le Chatelier, researches on quartz; Damour Coupeau, Chantepie, three papers on expansion of paste and covers; Granger, tungsten blue, and ceramics in Germany. And in the Bulletin of the same Society, Granger on soft porcelain, artificial or frit, 1913, and Cones, Fusible Cones and Seger Cones (1916).

A workman of Vierzon, M. Larchvêque is particularly interested in perfecting the production of porcelain. To him we owe interesting research in casting. He has published several reports of his work on raw materials used in the production of porcelain.

At the Manufacture de Sèvres they effected during the War notably important works on stoneware designed for chemical use. The Factory contributed its part in the National defense in making not the common pieces (those were in the domain of private industries), but the pieces difficult to attain with the resources at hand.

Its research laboratory has installed a control service for the French ceramic industries, but it has for its particular duty the direction of the workmen in the solution of technical problems.

PARIS, FRANCE

THE DEVELOPMENT OF CERAMIC TECHNOLOGY AND SCIENCE IN JAPAN

BY SEIJI KONDO

Early Ceramic Technology

The ceramic technology of modern times in Japan developed remarkably in the Meiji period, *i. e.*, 1868–1912. This country, in 1912, entered into friendly relations with other countries for the first time, and accordingly foreign technologies and new industries came to the Empire. However, the sound development of the imported technologies and industries has been chiefly in the past twenty-five years. During the Meiji period, most ceramists endeavored to imitate foreign processes. Of course,

technological and scientific researches were done in some organizations of the government and in other laboratories. The stoppage of import of various materials and goods due to the War caused great consternation among the people and the time came then to awake. Several research organizations and laboratories have since been established for ceramic industries. People are now hoping that Japanese scientists and experts shall hereafter develop the ceramic technology by themselves.

1. Japanese Ceramic Society (Dai-Nippon Yogio Kiokai)

The Society was founded on Oct. 10, 1891, by the graduates, professors and students of the Tokio Higher Technical School, with the purpose of advancing ceramic arts and of uniting ceramic people in the country. It is one of our prides that we have long used the term "Yogio" which means "industries using kiln" or ceramic industries as recently defined by the AMERICAN CERAMIC SOCIETY.

The present members include the graduates of ceramic schools, capitalists, dealers and those who are connected or interested with the industries. The meaning of "Kiokai" is association and not society as it is usually employed, but it is substantially changing to a true society, as almost all graduates of ceramic schools are joining it. Although the society was established by only thirty-seven members, it has now about fourteen hundred.

The Society has been pretty active during the past thirty years, thus: (1) It has published a monthly Journal for thirty years; (2) It has published many books which comprise "The Modern History of Japanese Ceramic Industries" of about three thousand pages; (3) It has held two great ceramic exhibitions in Tokio and (4) Lecture-meetings were held every year by its head-office in Tokio or its branches at Kioto, Osaka and Nagoya.

The present officers comprise of a president (Vice-Count Kentaro Kaneko), eighteen negotiators, twenty standing committees, three directors (Mr. J. Kumazawa, Mr. O. Umeda and Mr. T. Kuranashi), fifty-three councillors, two auditors, two secretaries, two treasurers and two editors.

It owes much to the late Dr. Jintaro Takayama, former general secretary, that the Society could develop to the present state. He is also one of those who has contributed most to the promotion of ceramic technology and science in Japan.

2. Research Organizations and Industrial Laboratories

The Department of Agriculture and Commerce has three ceramic laboratories, *i. e.*, the Third Department of Tokio and Osaka Industrial Laboratories and the Pottery Laboratory in Kioto. The Third Depart-

ment of the Tokio Industrial Laboratory which was founded in 1906 has served much in advancing ceramic technology. The others were established a few years ago.

There are six ceramic laboratories belonging to the local authorities. The Ceramic Experimental Works of the South Manchurian R. R. Co. at Dairen has served much in the utilization and development of the local mineral resources, and they have been very successful, *e. g.*, (1) they found magnesite, fire clays, quartzite, etc., (2) they have manufactured very fine glasswares and (3) they have manufactured porcelains and very good refractory bricks.

Besides, many companies have laboratories, of which the research laboratories of the Tokio Electric Co., the Asahi Glass Co. and the Onoda Cement Co. are most noted.

3. Educational Institutions

The Ceramic Department of the Tokio Higher Technical School is closely related with the development of the technology of Japan. The Department was organized by the late Dr. G. Wagner in 1881 and has long been sole organization for ceramic higher education. It has sent 317 graduates to the Oriental ceramic world, of which 31 are Chinese, and 42 of other nationalities who have completed special courses. The latter includes ten Indians, Philipinos and other foreigners. These some four hundred persons are playing most important rôles in far-Eastern ceramic fields. At present, the Department is educating 61 regular students, including 11 Chinese, and one special student. Besides, its laboratory has contributed much to the promotion of ceramic technology and science of the country.

Among other institutions the following are well equipped and are training experts: The Keijo Technical Special School, the Kyoto Pottery Training-School, the Ceramic School of the Aichi Prefecture, the Arita Technical School, the Technical School of the Ishikawa Prefecture, Pottery School of the Gifu Prefecture and the Technical School of the Fukushima Prefecture. We have six other similar schools. The Departments of Engineering Chemistry of the Tokio, Kyoto, Kiushu and Tohoku Imperial Universities are also giving lectures on ceramic engineering.

4. The Development of Ceramic Technology

Heavy Clay Products.—The industry of common brick in Japan arose about fifty years ago. Machines, driers and kilns were imported or built early by German experts and many big plants have been erected especially near Tokio and Osaka. Numerous small plants have also been working even in the vicinity of Tokio and Osaka, most of them using “Nobori-

gama" which is a semi-continuous kiln built on a slope. But these small plants have recently been absorbed or displaced almost entirely by big ones. As an example of well-equipped plants, I will describe a plant of the Nippon Brick Manufacturing Company, Tokio: They have there automatic proportioning and feeding apparatus, Cohr's driers improved by their experts, Keller's driers, Ring kilns and Haedrich's chamber kiln. The Osaka Ceramic Industries Co. has seventeen ring kilns.

We have a special face-brick whose surfaces are nearly melted by direct wood-fire and accord well with Japanese taste. A continuous kiln has been patented for massive production. The Osaka Ceramic Industries Company are manufacturing similar bricks by salt-glazing. Rough-surfaced bricks are now prevailing.

The sand-lime brick industry has not yet been successful in Japan; but slag bricks are made on a large scale at the iron works of the Government.

Small tiles, usually $4\frac{9}{32}$ " long, $2\frac{3}{8}$ " wide and about $\frac{3}{8}$ " thick, are most important materials for facing buildings and are used even for decorating wooden buildings. Accordingly, the demand for ordinary face brick has rapidly decreased in the past ten years. The tiles are usually stoneware or hard faience and rather rarely porcelain. Recently, the demand for wall tiles and floor tiles has rapidly increased.

Ordinary roofing tiles are burned in up-draft kilns called "Kawara-Gama." Pine-branches are usually fed into the fire-boxes at the end of firing and every opening is sealed to develop grey color and silver-luster on the surface. Although many patents have been granted for semi-continuous or continuous kilns which aim at the utilization of waste-heat and larger production, they remain still as one of the most important problems in our ceramic industries. Glazed tiles and fitting tiles are now produced in big plants.

Most of the pipes are made in primitive ways. However, several factories have been using screw pipe-presses. A plant with an American steam-press has just been completed. Hollow tiles are manufactured in several plants.

Refractories.—The manufacture of refractory wares in Japan arose in the early years of Meiji.

We have dark red quartzite which attains its maximum expansion very easily in heating. Its contents in ferric oxide range 1.4–4.8%.

Magnesite refractories have been a popular topic, since the mineral was found in Manchuria in 1913.

Very hard stones, occurring in or together with Roseki, have recently been found to be diaspore. Two typical kinds are:

	Silica	Alumina	Ferric oxide	Lime	Magnesia	Alkalies	Ig. loss
Kanakura diaspore.....	2.84	81.76	1.02	.....	.....	.....	14.36
Mitsuishi diaspore.....	6.37	78.72	0.28	.....	.....	.....	14.52

Recently a refractory clay, containing about 56% alumina, was found at Kochi in the Province of Rikuchu. It was ascertained by Prof. S. Kozu that the mother mineral of the clay contains 36.94% silica, 44.13% alumina, 0.08% magnesia, 0.50% lime, 0.05% titanium dioxide, 18.94% water and trace of phosphoric acid and therefore its chemical formula is $2\text{Al}_2\text{O}_3$, 3SiO_2 , $5\text{H}_2\text{O}$. He gave the new mineral a name "Kochite."¹

Stoneware, White Ware and Porcelain.—The Takayama-Kozan Potteries Co., manufacturers of chemical stonewares, succeeded in making very large vessels and complicated apparatus such as centrifugal fans.

Majolica faience, which was introduced by Mr. K. Hirano to our country and was manufactured at the Tokio Higher Technical School for several years, is now popular.

Mr. H. Matsumura was the pioneer in the manufacture of tablewares of hard faience. Mr. Y. Kitamura devoted several years to the study of the faience and contributed much to its development. The Toyo Toki Co., Kokura, are firing hard faiences in tunnel kilns. They are also the first Japanese manufacturers of high grade sanitary wares.

Porcelain which is a most important clay product in Japan is made of bodies composed of "Gairome" (very plastic kaolin) or "Kibushi" (shale resembling ball clay) together with pegmatite or feldspar and quartz in the Provinces of Mino and Owari, while manufacturers in Hizen, Kaga, Kyoto, Aizu and some other districts are using bodies composed chiefly of decomposed liparite or quartz-porphyry. According to a report of the Industrial Laboratory by Dr. Y. Kitamura, the composition of Japanese porcelain is 0.26–0.57 RO, Al_2O_3 , 4.68–8.21 SiO_2 which indicates excessive contents of silica or bases and silica. However, the manufacturers of high-grade tablewares such as the Nippon Toki Co., Nagoya, the Nagoya Seitoshō, Nagoya, and the Toyo Toki Co., Kokura, are probably using bodies composed of Amakusa (best liparite), kaolin and feldspar of first quality to make up the said defect and their chemical compositions are quite different from the common Japanese porcelains.

Most of Japanese porcelain is fired in wood-fired semi-continuous kilns. The Ceramic Department of the Tokio Higher Technical School built early coal-fired kilns for porcelain and it reported also in 1899 and 1901 the result of a continuous kiln consisting of five chambers. These reports led the manufacturers to the use of coal. Mr. K. Asukai, Mr. S. Momoki and Mr. M. Ezoe rendered great services to Japanese ceramic in-

¹ Koza, Seto and Kinoshita, *Jour. Geol. Soc.*, Tokio, 29, No. 339.

dustry in promoting the art of manufacturing tablewares of first quality.

The Nippon Insulator Co., Nagoya, and the Shofu Industries Co., Kioto, are most distinguished manufacturers of high-tension insulators. Insulators, chemical porcelains and refractory porcelains have long been studied and their qualities have constantly been improved.

Glass and Enamel.—The chief siliceous materials of glass are sand and volcanic tuft.

Soda-ash has long been imported chiefly from England. In 1917, the Asahi Glass Company, manufacturers of window glass, started an ammonia-soda plant.

Among other raw materials, selenium used as decolorizer is highly contained in Japanese sulfide ores and is now recovered from their waste products.

As to pot furnaces, gas-fired recuperative ones have steadily increased, though small furnaces of direct firing are still prevailing. Covered pots and "Japan Pots" like tea-pots are commonly used. Mr. Hirano of Dairen has recently succeeded in melting pure white glasses in open pots. The regenerative tank was introduced in 1889 and the continuous tank in 1906.

Since 1909, the Department of Agriculture and Commerce has imported various machines to lend free to glass manufacturers. Various bottle machines have been imported and invented since 1906, but the introduction of Owens' machines by the Nippon Glass Industry Company caused a heavy blow on their competitors. Two years later, Mr. T. Yamamoto imported several O'Neill's machines and a Lynch machine.

The Asahi Glass Co., established in 1907, were the first Japanese manufacturers who succeeded in the window glass industry. They have installed twenty-four of Lubbers' machines since 1914. The Nichi-Bei Sheet Glass Company started a plant in Kiushu in 1919 where Colburn's machines are used.

The industry of plate glasses arose in 1915 and they are produced by the Kiokuto Glass Industry Company which are connected with the Mississippi Glass Company.

Most of electric bulbs are manufactured by the Tokio Electric Company.

They are making Mazda lamps, projectors, shades, fixtures, etc. The research laboratory of the Company has succeeded in manufacturing optical, thermo-electric and simple lamp pyrometers, magnesia refractory tubes and crucibles, optical glass slab and circular disc, Audion, Plitron, pure fused quartz, thermometer glass, etc.

Chemical glasses like Jena wares have been manufactured since ten years ago.

The Naval Arsenal in Tokio started an optical glass factory at the be-

ginning of the War, Mr. R. Shibata as expert, and now several kinds of the glass are manufactured there.

Mr. T. Oi patented in 1916 a process of manufacturing bracelet. It consists mainly in drawing out the gathering which has a core with innumerable bubbles, produced by the addition of sodium bicarbonate to molten glass. A large amount of the goods has since been exported every year.

"Silk Glass" which is made by cementing two layers of thick threads to form a sheet has been manufactured since 1912.

There are many enamel manufacturers in Japan and large wares such as bath-tubs and chemical vessels are manufactured.

Cement.—Portland cement in Japan was manufactured first by the thin slurry process, using slaked lime and river-mud as raw materials. Soon the process was abandoned and the dry method came. Most of plants are now using limestone and clay or shale. In 1903, the Asano Cement Company, largest manufacturers in Japan, patented a process of manufacturing the cement by burning the raw mixture, composed of quick-lime and clay or silicates, in rotary kiln for the purpose of increasing the output of rotary kiln and the mill. Recently, a few plants were erected to utilize the waste lime, produced in the manufacture of ammonium sulphate from calcium cyanamide. Blast-furnace slag is also used in the cement factory of the iron works in Yawata. Several years ago, the Osaka Ceramic Industries Company started a plant of thick slurry process, with limestone and clay as raw materials. As for the grinding machines, the use of compound mills as Compeb is prevailing.

Rotary kiln, first installed by the Asano Cement Company in 1903, has steadily increased in its number and size, now two hundred feet kiln being most usual.

Waste-heat boilers and Cottrell's apparatus are used to utilize the waste-heat or to precipitate dust from rotary kilns and lime kilns in a few plants.

Cement specifications were issued by the Minister of Agriculture and Commerce on Feb. 10, 1905. It was modified on Dec. 10, 1909, and on June 20, 1919, as the quality of the cement has steadily been improved.

I am very sorry that time was too short to describe the development of ceramic technology during past twenty-five years in China. In short, it is now undergoing not a little influence from those in other countries. Many laboratories and educational institutions have recently been founded; for instance, the Provinces of Chihli, Shantung and Kiangsoo have each a Government Laboratory for ceramic industries and the Provinces of Kiangsi and Chenkiang have higher technical schools where ceramic engineering is taught.

ASAKUSA, TOKIO,
JAPAN

RESEARCHES BY ASSOCIATIONS OF USERS AND PRODUCERS OF CERAMIC PRODUCTS

ACTIVITIES OF THE AMERICAN SOCIETY FOR TESTING MATERIALS IN THE FIELD OF CERAMICS

BY C. L. WARWICK

Secretary-Treasurer, A. S. T. M.

The activities of the American Society for Testing Materials in the field of Ceramics date practically from its organization as a national society in 1902. In the year following was organized the Society's Committee on Brick. There then were organized committees on Sewer Pipe in 1904, Drain Tile in 1911, Refractories in 1914 and Hollow Building Tile in 1915. It will be convenient to discuss the Society's work on Ceramics under these headings.

Brick

The Committee on Brick, now designated Committee C-3, was organized in 1903, and for a period of five or six years made a general study of tests and properties of paving and building brick. In particular during that period the rattler test for paving brick was studied, and a paper by Edward Orton, Jr., was presented in 1905 discussing "The Rattler Test for Paving Brick as a Safe Method of Disclosing the Limit of Permissible Absorption." In 1910 the committee arranged for an extensive investigation of paving brick in which over 2,000 samples of the various kinds of brick were distributed among six testing laboratories. The primary object of the investigation was to study the rattler test and to relate the results of that test to freezing, absorption and porosity tests. The investigation was completed in due course and resulted in the Committee proposing Specifications for Paving Brick in 1913 which have since been adopted as standard.

Having completed the study of paving brick, the Committee then turned its attention to building brick and planned an equally comprehensive investigation. Samples of brick from the various producing centers were secured and tested for compressive strength, transverse strength, absorption and freezing, according to methods outlined by the Committee. These tests were made in the engineering laboratories of various universities and technical schools and served an incidental purpose of stimulating interest in the study and accurate testing of brick. Upon the completion of this investigation and based upon the results, the committee prepared Specifications for Building Brick that have since been adopted as standard. In presenting the specifications the committee included a paper by Edward Orton, Jr., entitled "A Study of the Proposed A. S. T. M. Tentative Specifications for Building Brick and a Correlation of Their

Requirements with Sodium-sulfate Treatment and Actual Freezing.”

More recently the Committee has been engaged in the preparation of Specifications for Clay Sewer Brick and has proposed specifications that the Society has accepted as tentative.

In coöperation with the Committee on Road Materials, the Committee on Brick is now engaged in a review and further study of tests and specifications for paving brick.

Some of the men who have been prominently identified with the activities of this committee are Logan Waller Page, as chairman from 1905 until 1910; E. W. Lazell, as secretary from 1905 to 1912; D. E. Douty, as chairman from 1911 to 1912 and secretary in 1913; A. V. Bleininger as chairman from 1913 to 1920; Edward Orton, Jr., as secretary from 1913 to 1920; H. T. Shelley, as chairman in 1921. The present officers of the Committee are T. R. Lawson, chairman, H. T. Shelley, vice-chairman, and W. E. Emley, secretary.

Sewer Pipe

The Committee on Clay and Cement Sewer Pipe, now designated Committee C-4, was organized in 1904. During the first four or five years the Committee conducted an extensive series of tests and divided its activities into three divisions: (1) A study of the demands made upon sewer pipe; (2) development of tests and specifications which will secure the materials and methods of manufacture resulting in pipe that will meet those demands; and (3) development of specifications for laying pipe lines under various conditions. Considerable progress was made in carrying out this program during the next few years, and in 1914 memoranda of Recommendations for Laying Sewer Pipe and Definitions of Terms Relating to Sewer Pipe were submitted to the Society. These have subsequently been adopted as recommended practice and standard, respectively.

In 1916, the Committee presented all the data that it had obtained up to that time on its schedule of investigation, and based upon this study, the Committee in 1917 presented Tentative Specifications for Clay Sewer Pipe, for Cement-Concrete Sewer Pipe, for Required Safe Crushing Strengths of Sewer Pipe to Carry Load from Ditch Filling, and also proposed revised Recommendations for Laying Sewer Pipe. The specifications were revised in subsequent years and are now, with one exception, standards of the Society.

The Committee is now engaged in studies of absorption and hydrostatic pressure test requirements; an accumulation of data and formulation of results affecting the chemical requirements of sewer pipe materials; and in a study of desirable changes in dimensions of sewer pipe and their permissible variations.

Some of the men who have been prominently identified with the activities of the Committee are Rudolph Hering, who has been chairman of the Committee since its organization, A. J. Provost, who has been vice-chairman since 1910, and G. T. Hammond, who has been secretary since 1918. C. F. McKenna served as secretary of the Committee from 1904 until 1910 and E. J. Fort as secretary from 1910 to 1918.

Drain Tile

The Committee on Drain Tile, designated as Committee C-6, was organized in 1911 to meet two very urgent conditions: (1) The comparatively recent development of the extensive use of very large drain tile in public drainage works for reclaiming wet lands, and the consequent unexpected discovery that these large drain tile were quite subject to cracking in the ditch under the weight of the ditch refilling, and (2) the comparatively recent introduction of the use of concrete drain tile on a large scale and the resulting controversy between clay tile and concrete tile producers as to the merits of the new material. Prior to the organization of this Committee there were no standard specifications for drain tile worthy of the name. Engineers had been in the habit of devoting a paragraph to drain tile in sewerage specifications, and drainage engineers had been trying to specify more definitely the qualities of drain tile. The Iowa Engineering Experiment Station had previously been engaged for some four or five years in the investigation of the causes of cracking of large drain tile in ditches, which served as the basis for certain specifications for drain tile and for methods of testing subsequently adopted as standard by the Iowa State Drainage Association, the Iowa State Engineering Society, and others.

The first task of the newly organized Committee was to plan and conduct an extensive series of investigations covering methods of tests, the determination of desired quality and durability of drain tile, and a study of methods of manufacture and construction and field specifications. In this work the Committee was assisted by a number of engineering laboratories and by the manufacturers of both clay and concrete tile. These investigations, which extended over five years—from 1911 to 1916—are estimated to have cost over \$25,000.

In 1914, Committee C-6 prepared tentative Specifications for Drain Tile covering strength tests, quality, and requirements for strength of tile as used in ditches. These specifications were submitted and adopted with the understanding that they were not complete, particularly with regard to the requirements for absorption tests and freezing and thawing tests of tile. The specifications were adopted as standard in 1916.

Following the adoption of the specifications the Committee continued

an investigation of freezing and thawing tests, which resulted in an important modification of these requirements in 1921.

The Committee is at present engaged upon an investigation of chemical tests and chemical test requirements for drain tile to determine their resistance to the action of alkalies and acids in soils. The Committee is also studying the reduction of the number of standard sizes of tile, believing that the adoption of reduced number of sizes would cause and bring about a large saving in equipment, stock on hand, interest on investment on stock and plant and the cost of changing machinery in the manufacturing of the various sizes.

Some of the men who have been prominently identified with the activities of the Committee are Prof. Anson Marston, who has served as chairman since the organization of the Committee, and Mr. J. T. Stewart, secretary from 1911 until 1921. The present officers of the Committee are Anson Marston, chairman; G. W. Pickels, secretary; D. A. Abrams, assistant secretary.

Refractories

The Committee on Refractories, now designated as C-8, was organized in 1914. The Committee devoted the first three years to a general study of methods of testing refractories and in 1917 recommended proposed Tentative Methods for Ultimate Chemical Analysis of Refractory Materials, proposed Tentative Test for Refractory Materials under Load at High Temperatures, and proposed Tentative Test for Slagging Action of Refractory Materials. In the following year the Committee recommended a Tentative Method for Porosity and Permanent Volume Changes in Refractory Materials, and in the following year a Tentative Method for Determination of Softening Point of Fire Clay Brick and Tentative Definitions for Clay Refractories. The purpose of these definitions, which relate to the resistance to heat and constancy of volume of clay refractories, is to classify refractories into the following four groups: High heat duty brick, intermediate heat duty brick, moderate heat duty brick, and low heat duty brick.

In 1920 the Committee proposed Methods of Analysis Covering Chrome Ore and Chrome Brick, and in 1921 Methods of Test for Resistance of Fire Clay Brick to Spalling Action were proposed. All of the methods and definitions above mentioned have been adopted as standard save those for Slagging Action and Resistance to Spalling Action, which are still tentative. The reports of the Committee during these years have contained results of a number of important investigations, among them one on the "Slagging Action of Refractory Brick," by Messrs. C. E. Nesbitt and M. L. Bell; a paper by R. M. Howe entitled "Vital Factors in the Testing of Fire-Clay Refractories," and a paper by W. A. Hull on the

"Status of Thermal Conductivity in Specifications for Refractories;" and in 1922 a report on Precision and Tolerances as applied to the various methods of test prepared by the Committee.

The work of the Committee on development of test methods represents but one side of its activities. As a preliminary step to the preparation of specifications for refractories the Committee has planned a survey of the requirements for refractories in the various industries, which it is necessary to undertake for each specific industry before it is deemed possible to write acceptable specifications for use in that industry. Pending the development of this side of its work the committee is continuing the study of test methods.

Some of the men who have been prominently identified with the committee are A. V. Bleininger, as chairman from 1914 until 1921; C. W. Kanolt as secretary from 1914 to 1916; W. H. Fulweiler, secretary from 1916. The present officers of the Committee are R. C. Purdy, chairman, W. H. Fulweiler, secretary.

Hollow Building Tile

The Committee on Hollow Building Tile, designated as Committee C-10, was organized in 1915. The Committee planned an investigation of clay hollow building tile and reported upon the scope of the work and the investigations under way in 1917. The results of compression and absorption tests and tests of tile walls were presented to the Society that year. Tentative Specifications for Clay Hollow Building Tile and Definitions of Terms Relating to Hollow Building Tile were submitted in 1921. Both of these are still in the tentative stage. The Committee is continuing its investigations in studying the physical properties of hollow building tile with special reference to their fire resistance. Data obtained in this investigation will undoubtedly greatly influence the future development of specifications and tests for building tile.

Some of the men who have been prominently identified with the activities of the Committee are L. H. Provine, as chairman, and E. V. Johnson, as secretary, from 1915 to 1920; W. A. Hull, as chairman, and C. C. Crockett, as secretary, from 1920 until the present time.

Conclusion

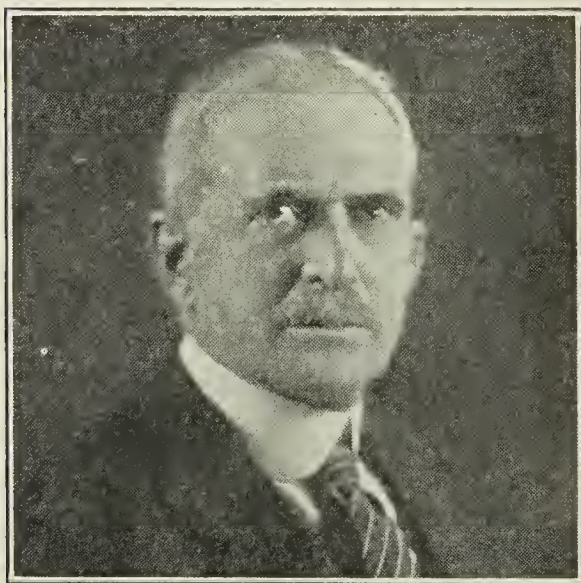
The investigations of these five Committees undoubtedly have stimulated research and investigation in their respective fields. Not only do the reports of the Committees contain much information of value in addition to the specifications and methods of test that were prepared, but the *Proceedings* of the Society also contain many papers dealing with clay products that have served materially to advance our knowledge of them.

THE INFLUENCE AND ACHIEVEMENTS OF THE NATIONAL BRICK MANUFACTURERS' ASSOCIATION ALONG TECHNICAL LINES

BY THEODORE A. RANDALL

The National Brick Manufacturers' Association was the first organization created in the United States to offer a forum for the discussion of manufacturing and technical problems on a national basis, drawing information from all parts of the country. Through its conventions and its published papers it created the nucleus of a technical literature. Its membership comprised the most intelligent and progressive men of the structural clay industries, men of extraordinary high qualities. The N. B. M. A. attracted also technically trained men like Orton, Lovejoy, Richardson, Wheeler and others who were glad to participate in its work.

The pioneer instinct of the country, the love of new business ventures, the cheerful undertaking of unknown risks, the sturdy independence



THOMAS E. WILSON, Pres. N. B. M. A.

of the small brick and tile maker, real good fellowship and hearty good will—all found expression in this Association. It therefore has a real history which is as much part of the industrial and technical development of the country as the latest contributions on technical subjects.

Many of the original papers must still be referred to if a correct impression on certain topics is to be obtained. Attention is called to the work of Lovejoy on the dehydration of clay; that of Richardson on the dry press process and brick-making in general; that of Wheeler on the paving brick materials; the earliest work of Orton on the brick rattler and numerous other activities, chief among which was the establishment of the School for Clayworkers at the Ohio State University.

The initiative in this great pioneer enterprise was taken by a committee of the N. B. M. A. composed of D. V. Purington, W. D. Gates, W. D. Richardson and Theo. A. Randall. These gentlemen journeyed to Columbus on an invitation by Prof. Orton and had a conference with the University faculty. Each in turn was introduced by Prof. Orton and spoke briefly of the necessity for better technical education for clay workers. The University directors were so favorably impressed, Prof. Orton was authorized to add the branch of ceramics to the college course. From that initiative effort, by the representatives of the N. B. M. A., have grown the various schools and institutions of technical learning in ceramics in America.

As previously stated when Prof. Orton, Jr., first proposed the establish-

ment of a school of clay working at Columbus, the N. B. M. A. strongly supported him and it has always since consistently supported other schools and institutions which are for the advancement of the art. Primarily, it has always stood for technical progress by giving a hearing to the machine manufacturers, the brick and tile maker and the exponent of scientific knowledge. The knowledge of its membership may not always have been technical, but it represented actual experience, cheerfully and gladly offered, without which all theory is in vain.

After the establishment of the Ceramic Department at the Ohio State University, its Director, Prof. Edward Orton, Jr., became still more closely associated with the N. B. M. A. and in coöperation with Professors Talbot and Hatt completed the first standardization of the rattling machine for the testing of paving brick. The Association then established a scholarship at Professor Orton's institution, a position filled in succession by a number of students, who later made names for themselves in the industrial and academic world.

The first holder of the scholarship was Albert V. Bleininger, followed by Ross C. Purdy, C. H. Griffin, Homer F. Staley, A. P. Potts and others. In the course of the work of the N. B. M. A. scholarship at the Ohio State University a number of investigations were conducted on the effect of the brick structure with reference to the rattler test, the effect of carbon and sulphur on the burning process, the drying of clay, etc.

Prof. Orton gave this his closest attention and the result was that from it resulted probably the masterpiece of all his subsequent researches, that well known classic, his investigation on the Oxidation of Carbon in Clays. It would be difficult to compute the value of the results of this study to the clay industries of the country and the world, but it must be many, many millions of dollars. Through the rules for governing the burning process as laid down by Prof. Orton, fortunes have been saved and the firing of clay products reduced to a rational basis. This work of Prof. Orton's, though the result of his own genius, still was done under the auspices of the N. B. M. A., and it is a source of no little pride to its membership to be able to enjoy this reflected glory.

Finally, with the growing interest in technical ceramics a number of our members were active in the founding of the AMERICAN CERAMIC SOCIETY, following the meeting at Pittsburgh in 1898, among whom were Prof. Edward Orton, Jr., W. D. Richardson, Ellis Lovejoy, Prof. H. A. Wheeler and A. V. Bleininger.

The technical work of the Association has always been kept in the foreground as much as conditions would permit. Many descriptions of plants or new processes are recorded in its *Transactions* and numerous reports have been issued on technical matters contributed by the Federal Bureaus, principally the Bureau of Standards. Among the really big things

which have been accomplished is the coöperative work with the latter Bureau on the testing of large size brick piers, probably the most extensive work along this line ever done anywhere in the world.

Many other reports on technical subjects have appeared in our transactions from architects, engineers and geologists and the members of our ceramic faculties. As a whole then, the history of the National Brick Manufacturers' Association is that of a technical organization, imparting to its membership technical information in plain terms and seeking to place its business on ever higher levels. Its Committee on Technical Investigations, though sadly handicapped by lack of funds, has kept the spark of research alive.

INDUSTRIAL DEVELOPMENTS

If scientific research is of value, what has it done for the ceramic industries? Have changes in conditions or methods resulted from the past twenty-five years of ceramic research and education? Such questions as these are not evidences of doubt; they are signs of a willingness to stand for a searching analysis of the situation.

Ceramic concerns are today searching for trained ceramic engineers to superintend and manage plants, and particularly to have in charge plant control. This is true in enamel, glass, brick, tile, refractories, terra cotta, pottery, and indeed in all ceramic lines. In contrast to this present demand for trained ceramic engineers, there was very little tolerance for them twenty-five years ago.

Increased production and increased wage cost, more than any other factors, have brought the necessity for supplanting hand labor for machine methods. These two factors have forced a change from dependency on the bigoted "experts" and skilled artisans, with their limited stock of secret knowledge, to charted organizations, control records, and an appreciation of the value of exchanging information. The ceramic industries are rapidly acquiring freedom from dependence on special knowledge and skill of an individual, and are requiring to an increasing extent that their directing employees shall have sound technical judgment and leadership based on ability to learn and to marshall the fundamental scientific and engineering facts to the solution of manufacturing problems.

It is true that there were several individuals twenty-five years ago who could produce a certain ceramic object of most excellent quality, but such individuals rarely succeeded in producing on a quantity basis. Such "experts" are not regarded so highly today, and in their place are the ceramists of broad training in the fundamentals of the sciences and engineering, or of science and art as applied to ceramics in general. Organized collaboration has displaced individual "experts."

A ceramist broadly trained and of excellent executive ability cannot alone meet the requirements of present day manufacturing. He is dependent upon the equipment manufacturers, the producers of materials, the research men in universities, bureaus and institutes, and upon the equipment, material and research men in allied industries. It is through collaboration and exchange with scientists and technically trained industrialists generally that our ceramists have the ability to replace the erstwhile "expert." Success in manufacturing is not now built upon the secrets possessed by an individual, but upon an organization that keeps in touch with the developments in science, engineering and art generally, and has the knack of making industrial applications of the things learned.

The improved machinery, kilns, dryers, and, in fact, all factory improvements result from adaptation of the findings of many contemporaneously working scientists, engineers, and artisans. No ceramic manufacturer can in truth say that no advantage has accrued to him from the vast investments of time, money and energy in fundamental and applied researches which have been made, and which are, on a much larger scale, being made today.

The promptness with which the ceramists produced a spark plug which would successfully meet the severe requirements in aeroplane motors, and the promptness with which the collaborating scientists and ceramists produced excellent quality optical glass during the recent War, are not without parallel in achievements of ceramists in other lines.

There is no art or skill in potting or in brick making ever known that is "lost" to the present day ceramist. They have maintained standard quality in *all* ceramic products and have made great improvements in quality in many. This, in spite of the supplanting of the low production of the hand methods of the highly skilled artisans by high production of machine methods with only average labor skill, is one of the benefits to the industries from researches and from exchanges through associations of scientific and technical knowledge.

A recital of some of the advantages which have accrued to the ceramic industries is given on the following pages.

ARTISTIC GLASSWARE

BY FREDERICK CARDER

One cannot review the advances made in blown artistic glass in this country during the past twenty-five years without looking backward a few more years.

It was in the early eighties that a renaissance of the glass industry commenced in the English speaking countries. The 1851 Exhibition held in London gave the necessary impetus to the revival of this most fascinating art, and to such men as Benjamin Richardson, Wilkes Webb and John Northwood, is this principally due.

Benjamin Richardson gathered around him young men whom he inspired with a love of their craft, whether in making, cutting or painting, and later etching which was then a new type of decoration.

John Northwood was a pioneer in this art, designing and developing numerous machines and processes. After designing and carving a vase with a copy of the Elgin frieze in relief as a principal motif, he conceived the idea of duplicating the Portland vase in glass, the same size and color as the original in the British Museum. This he successfully accomplished

after many failures. He was the first to polish cut and engraved glass by the use of hydrofluoric acid.

This carved or sculptured glass was taken up by Wilkes Webb who gave it a great amount of thought and energy, placing it successfully before the public.

Artists of other countries were not slow to avail themselves of this new art craft, and chief among them stand out Émile Gallé and Daum Freres of Nancy.

The works of these men raised the glass industry to a higher level in their own country as well as abroad.

About 1883 colored glass articles made entirely at the fire began to make their appearance. Investigations in colored glasses were conducted in England from 1883 up to 1900 by the aid of a Fletcher Gas Furnace of the same type that Abbe & Shott of Jena used for their investigations in optical glasses about the same time.

Mention should also be made of the pioneer work of Harry Powell of London who not only made some exquisite work in thin blown glass in delicate shades of color, but who made the glass mosaics to the designs of Sir W. B. Richmond for Saint Paul's Cathedral. Up to this time glass for mosaics was only made in Venice.

From 1883 up to the present time, a gradual progress can be discerned.

During this period cut glass was slowly being manufactured in this country by imported artisans and with imported European blanks. Later, as fine sands were discovered in the United States, manufacturers began to make their own blanks and ultimately were able to beat the European product in point of crystal clearness and color, owing chiefly to the sands found in the United States being almost free from iron oxide.

The AMERICAN CERAMIC SOCIETY was hailed by the glass manufacturers of ability as a means of obtaining technical knowledge, and the improvements made in the ceramic industry were reflected in the sister art.

The introduction and use of the Siemens Regenerative Furnace made possible more constant and dependable temperatures, together with the discovery by Le Chatelier of the platinum pyrometer.

The invention also of the oil and gas glory hole or re-heating furnace was an important step. This enabled the workman to obtain quicker heats and to work with greater facility than was possible in the pot with its numerous interruptions of men gathering glass out of the same pot. The furnace is now only used to melt the glass.

The most important artistic advance in this country at this time was made by John La Farge in his opaline glass. Examples of his church windows made from this beautiful material were exhibited at the Paris Exhibition in 1889. Following this was the invention of Favrile glass, the product of the Tiffany furnaces, and later, Aurene glass made by another

firm. This glass was a distinct advance from an artistic as well as from a chemical point of view, emulating the gorgeous effects of ancient glass which through decay or devitrification produced colors of prismatic hues. These effects of coloring are now obtained at the fire by the aid of the oil and gas glory hole which were impossible before.

The decorations are chiefly of superimposed glass either in threads or dabs, wrought while hot into a great variety of patterns and emphasized by the beautiful play of iridescent colors, obtained by the reduction of the rare metals dissolved into the mass. Such effects rival the peacock in their metallic sheen.

The cut glass industry became one of considerable importance and the products were highly thought of by the public. In fact American cut glass was considered in Europe of particular excellence.

It gave employment to a large number of artisans, until some years ago, a few manufacturers, influenced no doubt, by the American cry of production, decided to make cut glass on a ton basis, by what is known as pressed figured blanks, where the patterns are pressed or stamped upon the article, and then cut over.

This machine idea of making artistic glass (that is if cut glass can be claimed as such), was the means of putting it out of fashion, and removing it from the pedestal it formerly occupied in the public estimation.

The name rock crystal for polished engraved work, was given about 1883 to work of this character by some English manufacturers who were influenced by the fine collections of real rock crystal in the Louvre and other museums. Beautiful work of the engraver's art in table glass has been turned out by English factories. As the best and finest of these came to this country, it naturally gave a stimulus to our manufacturers to work also in the material, some of their products being of high order.

Intaglio or stone engraving was the next step, the designs being bolder and not so delicate as the engraving with the copper wheel.

Coincident with the growth of electric lighting in the United States and the adoption of high candle power lamps, a decided improvement was made in glassware for shades and bowls. These shades were made in soft colors with the decorations applied at the fire, giving a very pleasing effect when used to shield the excessive brightness of the electric light. These had a considerable vogue until some manufacturers made cheap imitations in paint which were sometimes fired but many of them merely dried.

Later came the semi-indirect bowl made first in alabaster glass, the revival of a glass that was used about 1851 for vases. Many of these bowls, although made in pressed glass, were artistic in design but cold in color. This was followed later by using glasses of softer and warmer tones which gave better and more artistic results, especially so, as more attention was given to the designs.

Lighting goods of this character obtained an excellence in this country far surpassing the products of Europe.

Just before the War, owing to cut glass going out of fashion, a return to Venetian glass was made with its wealth of color and form, together with its appropriateness in fitting in with home surroundings.

There had been, however, a small amount of similar glass made by one factory in the United States for some years prior to this date. It gave them an opportunity that they had long hoped for. The results were that a distinctly new type of artistic colored glass was designed, that was taken up by the public with enthusiasm.

Other factories have since turned their attention to the making of colored glass, one or two making a good product, while others are making it cheap and hasty—this latter tendency on the part of some American glass manufacturers is deplorable, and, as in the case of cut glass some years ago, can mean only one thing, *ruin to the industry*.

As Ruskin said, "A disposition for cheapness and not for excellence of workmanship, is the most frequent and certain cause of decay and destruction of arts and manufactures."

Let us hope that the American manufacturers will look to it that this beautiful art craft is fostered and encouraged.

CORNING GLASS WORKS
CORNING, NEW YORK

THE INFLUENCE OF THE AMERICAN CERAMIC SOCIETY IN THE TERRA COTTA INDUSTRY

BY W. D. GATES

In bringing team work into the industry, this SOCIETY has done a wonderful work for the terra cotta interests, as well as those of all the other divisions. Until its formation there had been too much secrecy and the work and research was individual. Each man had to attack the whole wide field and his time was so short and the field was so broad that it was impossible for individual effort to accomplish much. By the broadcasting of experimental work, that has come about from this SOCIETY, each man profits from the work of each of the others, is helped by them and in return helps them, and in this way a wealth of information is obtained and distributed. In the past, if a man made progress in the art, or made an important discovery, it was locked in secrecy and either perished with him or passed into the hands of someone incompetent to put into it the vim necessary to its successful development and use. There was no literature for the art. What discoveries were made were soon lost and there were long lapses when the art seemed dead until revived by some strong character, only to lapse again and die out. This SOCIETY built up among its

members appreciation and love of their art as the supreme achievement, placing the good of the art above their individual interest, thus making it permanent and lasting, a perpetuated and lasting art, to be used and built up constantly by future generations by giving them the results of our experience on which they might build up still greater achievements.

This has also resulted in the education of the public to their realizing that ours was indeed an art, that in its upbuilding we were using skill of a high degree, scientific attainment equal to or surpassing other arts, and an enthusiasm unequalled elsewhere. They are coming to realize that we are taking an inert, commonly distributed material, and are impressing on it our individuality, the very best that is in us, and doing it earnestly and enthusiastically. We are impressing on an imperishable material the results we have acquired from this SOCIETY, earnestly studied out and used enthusiastically, joyful in our work, glorying in it, so that what we have wrought into it will not only be a joy to people now living but will be passed on from generation to generation.

Half a century ago men in Italy were digging clay, selecting, experimenting, enameling and burning, and Della Robbia, seeing its possibilities, took what they had and wrought into it his visions and conceptions and thus left a priceless treasure to the world. Other clay like it still remains unused today, but because of the good work of the diggers, the mixers, the enamellers and burners, topped with Della Robbia having taken the results of all their skill and then impressed into it his personality, the very best that was in him, his visions and conceptions, the world has been, and will be for all time, richer and better.

CHICAGO, ILLINOIS

THE ROOKWOOD POTTERY COMPANY

BY STANLEY G. BURT

The desire to develop a distinctly American pottery led Mrs. Maria Longworth Storer to found the Rookwood Pottery in 1880. Her aim from the start was to get rich warm colors. The great desire of the pottery artist at that time was a white body, then an overglaze decoration as perfect as possible, but one that must never entirely conceal this so desirable white body. As a distinct innovation Rookwood started with a colored body, yellow, red or blue-grey, and on this colored clay before it was burned painted with a great variety of colored slips. The pieces after being fired were dipped in glaze making the decoration underglaze work, not overglaze as commonly practiced.

When the method of atomizing these colored slips was discovered at Rookwood a new field was opened. Instead of the artist being confined to the color of the clay for background any color desired or various colors

could be atomized over the whole piece. This led to the colored clays for the body being abandoned. The finest rich colors were not obtained, however, until a new glaze colored yellow was used in place of the older clear colorless one. This perfected Standard Ware was so amazing to the judges at the Paris Exhibition of 1889 that they asked to have more ware sent over to prove it was not an accident.

While the Standard Ware used mainly browns and reds a new type was next made called Iris for which the artist chose cooler colors and a rich black, the glaze in this case being without color.

In 1896 Rookwood made its first matt glazes and at the Buffalo Exposition of 1901 not only showed a wide range of colored matt glazes but vases painted by its artists using these colored matt glazes as an inlay. Nothing at all like these pieces had ever been made before. As a matt glaze is ordinarily opaque all underglaze decoration was concealed. The years of experience in underglaze slip painting were too valuable to lose so the Rookwood vellum glaze was next developed and shown at the St. Louis Exposition in 1903. It was said to be the only ceramic novelty there. With this glaze the artists were able to return to slip painting on the wet clay. This was fired as usual and then given a dip of vellum glaze and fired again. These pieces came from the kiln with the matt surface desired and with all the decoration easily seen through the glaze.

For the perfect development of these matt glazes a most carefully controlled fire was necessary. As Rookwood was probably the first American factory to use Seger cones, starting in 1895, and as the electric pyrometer was also in use at that time these with oil for fuel made it possible to have very accurate firing.

With the matt glazes perfected Rookwood started its Architectural Faience department. Here the main idea might be called mural decoration. Bright glazes on large flat surfaces are objectionable owing to surface reflections. This the matt glazes entirely avoid. A very interesting field is offered here for the artist, a large wall to be decorated presenting new problems in sharp contrast to those presented by vase decoration. In decorating the faience the artist paints with colored glazes instead of with colored slips.

At present while a great variety of matt glazes differing in texture and color are made on vases not painted by artists, the painted ware shows a partial return from matt to the bright glazes. This ware is called Soft Porcelain. The body used is new but the chief study has been in the choice of glazes. The colored grounds always used at Rookwood before are often lacking, the inspiration coming largely from the old Chinese porcelains.

Rookwood was the first to use crystalline glazes for pottery decoration. The Tiger Eye shown at Paris in 1889 has its crystals deep in the glaze

and not more on the surface as shown by those which appeared later from other factories.

Rookwood has received many honors and among these Gold Medal, Paris, 1889; Highest Awards, Chicago, 1893; Grand Prize, Paris, 1900; St. Petersburg, 1901 and Turin, 1902; two Grand Prizes, St. Louis, 1904.

ROOKWOOD POTTERY Co.
CINCINNATI, OHIO

SOME EARLY EXPERIENCES IN ENAMELING CAST IRON

BY E. S. DAWES

So far as the early history of the enameling industry is concerned, I know but little outside of the sanitary line, and do not know if I can give any information of interest to the SOCIETY. My knowledge began just forty-four years ago this month. At that time the J. L. Mott Iron Works were the only people in this country who made any pretense to make enameled sanitary ware, and I do not know if they had aspired to a bath tub as early as that.

But in 1879 the Standard Mfg. Co., in whose employ I was, first as a bookkeeper, and after as manager, made one to two cast iron tubs per day. We had but one style that was known then as the "Prison" tub. They were too cold for comfort, etc. Of the two tubs per day, there were but few enameled; the greater part of the production being painted and galvanized.

The old River Avenue property in Allegheny (now Pittsburgh) was built about 1870 by Ahlborn, Hartje, Wiley & Co., who made enameled stove (cast iron) hollow-ware. They failed in the panic of 1873 and in 1875 the property was bought at sheriff's sale by the late James W. Arrott and Francis Torrance and operated as the Standard Manufacturing Company. Mr. Arrott was father of the Arrotts who now own and run the U. S. Sanitary Mfg. Co., and Mr. Torrance was father of the late Francis J. Torrance.

The Standard's business was about 95% enameled stove hollow-ware, the other 5% consisted in 3% miscellaneous castings, and about 2% in the plumbing industry—mostly in a couple of patterns of water closet hoppers and wash stands for factory use. But few of these were enameled, the majority being painted.

Up until this time there was but little known as to the making of enamel outside of a very soft leadless enamel for cooking utensils. But about 1879 the wood pump industry took on a boom, and created a large demand for enameled iron cylinders. This business was divided practically between a small enameling concern, a split from Ahlborn, Hartje, Wiley & Co., at the time of their failure, and the "Standard," and it was soon learned

that in the soft glass used in the hollow-ware industry, the soluble constituents in the enamel or glass dissolved and the enamel became so rough that it would wear out the leather suckers. This was about the first time there was a necessity to put some thought into the why's and wherefore's of the ingredients to make a non-soluble mixture and it was the first effort on our part to eliminate the soluble fluxes and incorporate insoluble ones.

This pump cylinder business flourished for several years until drawn brass tubing took the place of the enameled cylinders. Now, with the loss of this business it was necessary to find something to take its place, and this was the time and opportunity to embark in the manufacture of enameled plumbing goods. About 1883 or 1884, the Standard added to their line several styles of lavatories, water closet hoppers and one pattern of bath tub. This was made in what was then known as the French pattern, and the design followed closely the pattern or design of the old copper tub. It was made with a hard-wood rim fastened on with wood screws and the molder who could make such a tub was considered very skilful. We (the Standard) started an aggressive campaign to make a business out of the plumbing industry. To encourage the jobbing trade we guaranteed stocks in warehouses against defects, damage, price, etc.

In embarking in the manufacture of tubs and other plumbers' ware, it was necessary to discontinue the use of the hollow-ware enamel and to make enamel that was white and flexible enough. The cylinder and hollow-ware enamels were blended. Up to this time what ware had been made by the Mott Iron Works was first coated with a very soft and porous coat, known as bone coat, that was so porous it took on rust, which showed through the enamel as a discoloration, similar to lime spots. The manner of applying the enamel was by mixing it with alcohol, which would evaporate quickly, and floating it on the ware. This proved a very unsatisfactory process, but as long as the business was limited there was no object in trying other ways.

It was about 1882 or 1883 that August Haarlander, who was the enameling foreman, and the writer commenced experimenting to make an enamel that we could dredge on the article, as is now done and which with improvements and modifications is the method followed today. Even at that time there was but little thought of the ultimate future of the industry. At the time I severed my connections with the Standard Company we had not made more than 10 or 15 tubs per day, and lavatories in proportion.

In 1887 the writer, in company with the late W. A. Myler, who was the accountant of the Standard Mfg. Company from 1881 until 1887, built the plant at New Brighton, Pa., known as the Dawes & Myler Works. Even at this time the growth in the business had been so slow that we started to make enameled stove hollow-ware, and it was not until about 1890 that we put in patterns to make bath tubs. From that date the business

grew rapidly, so rapidly that when in 1893 the New Brighton factory was burned, in rebuilding, the plant was constructed to make enameled sanitary goods exclusively. The demand for enameled baths, lavatories and other sanitary goods having increased to such an extent, it was necessary to find means to increase production and at the same time to reduce costs so that the modern appliances would be in reach of the masses.

The output of the enameling plants of the country prior to 1900 was very small compared to present day production. There were fewer plants and the capacity of each plant was small. The production of bath tubs by the Standard Mfg. Company, which was the largest producer in the world, was 45 tubs per day in 1893 and about 150 per day in 1899. This appears small compared to the present capacity of 2000 tubs per day of the Standard Sanitary Mfg. Company.

Shortly prior to 1900, John C. Reed, who was then manager of the Standard Mfg. Co.'s plant in old Allegheny, now North Side, Pittsburgh, Pa., conceived the idea of making tubs by what is commonly known as the match plate system. The process was new and unique and was patented by him. About the same time James W. Arrott, Jr., patented an automatically actuated dredger. By these two inventions the output was largely increased. Prior to that time a moulder would make two bath tubs per day. By the Reed process four men produced some 36 tubs per day of 8 hours. The automatic dredge added largely to the speed of the output which up to that time was a bath tub per hour or 24 tubs per furnace per day of 24 hours. With this, other improvements were injected into the shops: a mechanically operated table on which the red hot tubs were enameled, with other improvements from time to time, have cut the working force on a furnace one-half. Then the furnaces that could heat only one tub an hour were improved upon from time to time, until at present time 3 to 4 tubs per hour are obtained. While these improvements in way of manufacturing were going on, the management was making improvements in designs. At first the tubs were made with wood rims. From wood the enameled roll rim was evolved—from the tub on feet, the one-piece tub, enameled inside and out, changing the bath room from a room for bathing purposes only into the pride of the house owner. The lavatory with the slab and bowl cast in two pieces and butted together, making an unsanitary and unsightly job, has grown into the beautiful one-piece lavatory of the present day.

While a number of the men who laid the foundation for the large industry of the present day have passed away, the real life of the business is so recent that the ones who were so instrumental in its growth, are still actively engaged in the business. As a finality, what I have passed over is the organization of the Standard Sanitary Mfg. Co. in 1900. At that time the largest producers of enameled sanitary ware in the country were the

Standard Mfg. Co., of Pittsburgh, Pa., the Ahrens & Ott Mfg. Co., of Louisville, Ky., and Dawes & Myler of New Brighton, Pa. At the time of combining to form the Standard Sanitary Mfg. Company they bought up several other concerns, consolidating such equipment as could be used in the three plants. The plants thus bought were scrapped and sold.

From the time of its formation this Company has maintained its position as the largest producer of enameled iron sanitary ware in the world, and has contributed its share to the development of the industry during the past twenty-two years. However, just as we realize that others besides ourselves were instrumental in founding the sanitary enameling industry in this country, just so we are fully aware that other concerns have furthered its later development. We take this occasion to express our appreciation of the ability and energy of our competitors.

2305 COMMONWEALTH AVENUE
CHICAGO, ILL.

EARLY HISTORY OF ENAMELING IN THE VOLLRATH COMPANY

BY C. A. W. VOLLRATH

Enameling, I feel justified in saying, is an intricate art, as the experienced enamer well knows and as the novice is ready to admit. The adhesion of a hard porcelain coating to a metal body of radically different physical characteristics demands the best that science and practice have to offer, and makes the subject one which will always be of interest. Naturally, research work will give beginners a valuable foundation in bringing out many facts well known to older enamellers. On the other hand, and because of the secretive nature of the business, the older enamellers have possession of information pertaining to enamels for certain uses which new men in the field do not have.

During my personal experience in enameling, covering a period of approximately fifty years, so many theories and so much experimental work has been advanced and discarded that to attempt to assemble and enumerate this data would be well-nigh impossible. My experience in the development of porcelain enamels I admit has been unusual and uncommon to many of those now in the field, and had this data but been recorded by me, it would today be productive of data of interest and much interesting reading, but I have never recorded these facts.

Prior to 1874 my father was a foundryman and a manufacturer of steel. It was in 1874 that he first built his plant for the manufacture of cast iron enamel ware, from which time my personal experience more distinctly relates.

In 1867, when I was a youth, I very vividly recall an experiment made by my father in attempting to coat a previously heated cast iron pan with

a molten mass. He so manipulated the pan and mass as to evenly distribute the latter over the surface of the pan, allowing the surplus to run out and subjecting the pan to a reheating. The mass in the mix was red in color, leading me to believe that, no doubt, red lead in quantity had been used. The experiment must have been unsuccessful, since nothing developed from it. My youth prevented me from knowing the full details of this experiment.

It was in 1870, after extended experiments and progress in enameling, that we secured in Europe interesting and valuable formulas. The frit ground coat was not greatly different from that used today, the glaze was softer than those of present origin. Silica, mica, soda, borax, kryolith, potash and saltpetre furnished the minerals and fluxes, with clay on mill for white enamel, and without clay for gray enamel.

At that period ground coats were fritted in muffles, the glaze enamel was melted one, two and three times in clay crucibles, with small holes in the bottom of the crucibles through which the molten mass passed. Four crucibles were usually placed in the melter, and the mix was continually fed into the crucibles.

In this period the grinding mills were made of granite, each mill having one runner for wet grinding. Cast iron muffles also were used for burning.

It was in 1880, I believe, that glazes were made with feldspar, silica, borax, kryolith, soda, saltpetre and tin oxide, with clay in the mill for white enamel.

It was about this same period also that vat smelters were used for the glazes, and about this time gas-fired clay-tile muffles for firing the ware were built. About this time one of the first dry pulverizers (pebble mills) made in the United States was installed. The hollow-ware castings were enameled outside as well as inside. A variety of finish coat enamels were made, including speckled enamel. Specks were made by adding oxides of manganese or cobalt in quantity to a mix and grinding dry, and then by adding a certain per cent of this mix to an enamel mass, these specks would appear after firing. This method of producing specks I patented in the year 1889. (This enamel is being produced today by several manufacturers.)

All through these years hollow-ware had been cleaned before coating by milling with broken pieces of iron, or scouring by hand or machine-scoured with sand and water. Pickling cast iron was also a common practice, but the nature of the ground coat produced no end of defective ware when pickling was resorted to in wet process enameling. With recognition of this fact, many have resorted to sandblasting in an attempt to avoid these defects. Bath tubs and sinks at this time were always pickled, ground coated and dry powder applied when heated. Any other method, as wet white ground coat and glaze wet applied, developed an enamel finish of uncertain quality on bath tubs and sinks.

Wet white ground coat with the powdered glaze rolled onto a heated surface was largely used on hollow-ware. The glaze was usually made of broken glass and borax melted to a glass, dry powdered and saturated with a solution of sal soda and again dried for use.

In 1892 sheet steel stamped ware was added to the Vollrath Company's line. Before this date steel was of such composition that, if pickled as today and coated with a present day ground coat, poor ware would be produced. With extraordinary care in annealing, pickling and the ground coat treatment, very fine sinks were made. This merely illustrates that successful enameling is by no means merely ground and finish enamel formulas, but rather a combination of all things entering into every detail of manufacture from source to completion. I cite this to show that the steel then produced in the United States was not fit for enameling. It was said at this time that the mottled-gray ware on metal direct, was so made with only English iron, and that no other steel ware was made in the United States until mild drawing steel was manufactured here. At this time there was a foreign patent for a mottled-gray enamel, placed directly on the steel, such enamel having a greater alkali content than was necessary for the same enamel on iron. This was no doubt the beginning of the spreading of this industry in this country.

About 1900 various colored wares appeared on the market, such as inside white, outside turquoise blue, outside copper-red. Today, the white-ware and white and mottled-gray wares are the most popular wares.

I believe in this period fewer changes have been made in enameling formulae than have been made in steel to make it more suitable for the enamellers. It has been the common saying among enamellers that one formula, no matter how good for its particular purpose in one plant, will not work in another plant when used for the same purpose. This merely illustrates the radical difference in the different processes and the vital importance of each, and in the final analysis the organization has much to do with successful ware.

Thirty years ago, Germany had three hundred enameling factories while the United States had but a few. Today reasonable protection and the increasing appreciation of the public of the value of enamel ware has built up the industry. Naturally, mechanical developments, such as gas welding, increased variety of sizes and shapes, improved enamel finish, have all contributed to this growth, and the public has developed more of an interest in sanitation in the kitchen.

It is not my purpose to deal with the late improvements in enamels, mechanical developments, smelter or muffle designs, with which you are familiar. The foregoing, however, briefly put, covers in part some of my experiences as enameler for the Vollrath Company. It is due to constant experiment in our search for something better that our product has reached

its present standard. It has been our policy to give direct and personal attention to the education of the younger generation in our organization in the intricate art of enameling, and impressing on all concerned the vital importance of each step in the process. By this process they will be given a start in enameling with my fifty years of experiment and experience in the background.

THE VOLLRATH CO.
SHEBOYGAN, WIS.

DEVELOPMENTS IN ENAMELING TECHNOLOGY DURING THE PAST TWENTY-FIVE YEARS

BY H. F. STALEY

The Founding of the Enamel Industry

It is evident that the foundations of modern enameling technology in this country were laid broadly and strongly in the quarter of the century between 1875-1900 and it would appear consequently that there was little to be done in the recent quarter of a century. It is true that the achievements of this latter period have not been as spectacular nor as fundamentally important as those of the preceding one. The opportunity to establish a technology occurs only once. Therefore, those of us who are engaged in the enamel business now and those who follow us will never have a chance to do such epoch-marking work as that done by the men of broad vision in the enameling industry during the last quarter of the 19th century. However, while it has not been possible to lay the foundations during the last twenty-five years, it has been possible for those engaged in the enameling industry during this time to rear a fine and noble superstructure on the foundations built by the previous generation.

The Achievements of the Past Twenty-five Years

The history of the technical development in the past twenty-five years has been marked not so much by startling new discoveries as by the development and elaboration of methods and practices established in earlier periods. This has led to the production of more durable and more beautiful enamels at less cost, to the speeding up of production, especially by the use of mechanical improvements, and in general to a lessening of the cost of enameled wares and a widening of their usefulness, which in turn has made possible the growth of the vast enameling industry of the present time.

For obvious reasons it is not possible for anyone to list with certainty, and with assurance of the approval of his readers, the outstanding tech-

nical developments in the enameling industry of the past twenty-five years. This is true not only because the importance of the various items will vary according to the personal viewpoint of the observer, but also because at this time it is not possible to forecast the future and to know the effect certain developments of this period will have on the future course of the industry.

Simply at my personal appraisal, I am inclined to list the following as the most marked achievements in enameling technology during the last quarter of a century:

1. The invention of the automatic dredge for dry coat enameling.
2. The introduction of machine molding of bath tubs.
3. The development of the use of antimony compounds in dry coat enamels.
4. The development of decorative enameling of cast iron by the wet process.
5. The formation of the Enamel Division of the AMERICAN CERAMIC SOCIETY.
6. The coöperative investigation of fish-scaling in enamels on sheet steel conducted by the Enamel Division of the AMERICAN CERAMIC SOCIETY and the United States Bureau of Standards.

The Automatic Dredge

The first two achievements were performed about the year 1900. They were therefore just on the border line at the beginning of the past quarter of a century and the end of the previous one. The marked effect of the invention of the automatically actuated dredge by Mr. James W. Arrot, Jr., has been described by Mr. Dawes. The introduction of this dredge with the other mechanical improvements that were naturally a corollary of its use, such as the employment of power driven enameling tables and mechanically operated furnace doors, cut the force necessary to operate a furnace in half and at the same time made the work of the remaining half of the force much easier and more endurable. Moreover, the few men now employed on a furnace can make twice as many pieces of ware as the large force formerly did. It is hardly conceivable that the cast iron enameling industry would have reached its present growth if it had not been for the introduction of the automatic dredge.

Machine Molding of Bath Tubs

The invention of machine molding of bath tubs by Mr. John C. Reed has also been emphasized by Mr. Dawes. Following Mr. Reed, others contributed to the development of machine molding and several methods are now in use. However, it appears that full credit for the original achievement belongs to Mr. Reed. The introduction of machine molding of tubs reduced the labor cost enormously, reduced the amount of equipment and floor space required for manufacture very much and at the same

time made possible the production of uniformly better castings. This achievement was fundamental to the vast expansion that has taken place in the sanitary enameling industry.

Use of Antimony Compounds in Enamels

The development of the use of antimony compounds in dry coat enamels in this country took place between 1905 and 1910. The compound in general use is sodium antimonate or mixtures of sodium antimonate with other chemicals; oxide of antimony has also been used to some extent. The value of the introduction of antimony compounds as opacifiers in enamels is still a question of debate among those engaged in the industry. Whatever we may think of the advantage of using these materials, the fact remains that the introduction of antimony compounds into enamel mixtures made necessary radical changes in enamel compositions and changes in the technique of melting enamels. Those engaged in the enameling industry met the issue successfully and large amounts of enameled sanitary ware of good quality are now being made in this country with the use of antimony compounds. To develop a technique for using successfully materials of seemingly such erratic behavior was a severe test of technical ability. The experimental work connected with the development of antimony bearing enamels was conducted at the same time in various factories. Therefore, it is not possible to give specific credit for this achievement.

Decorative Enameling of Cast Iron

A new technique of enameling stove parts and other articles of cast iron in a variety of colors by the wet coat process has grown up in this country during the last ten years. For the past seventy-five years, a certain amount of cast iron hollow-ware has been enameled in this country by the wet process. However, the enamels used were not comparable in elasticity and beauty of finish to those now being used for decorative enameling of cast iron. It appears that the introduction of this type of enamel is leading to what seemed impossible—a practically new enameling technology and a new enameling industry. It is the prediction of experienced stove manufacturers that within ten years the old black stove will have disappeared from commerce and that every stove made will be enameled. A great many other articles manufactured from cast iron are now being enameled by the wet process and it is probable that the use of such enamels will be greatly extended. The writer is not sure to whom the credit for the introduction of this type of enamel belongs. It seems certain, however, that Mr. Karl Türk was a prominent figure in the early stages of the development of this branch of enameling technology.

Formation of the Enamel Division

The establishment of the Enamel Division of the AMERICAN CERAMIC SOCIETY and the work by the SOCIETY that led up to the establishment of that Division was one of the notable developments in enameling technology during the past twenty-five years. The relation of the AMERICAN CERAMIC SOCIETY to the enameling industry dates back to the year 1906 when the first paper relating to enameling was contributed to the *Transactions of the Society*. The first few tentative efforts in the way of papers did not hit directly at the problems confronting the enamelers of the country and did not arouse much interest on the part of the enameling industry.

Beginning with the annual meeting in 1911 and the publication of Vol. 13 of the *Transactions* in the same year, a change was noticeable in the character of most of the papers published. The difference lay in the obvious effort to be of direct help to the enamelers by discussing the real problems of the enameling industry in language practical enamelers could understand. At first the industry was somewhat skeptical, but finally some came to understand the spirit in which we were working and realized that at least part of the papers read were worthy of study. Therefore, between 1911 and 1919 there was a gradual increase in the number of members of the SOCIETY from the enameling industry.

The Enamel Division was organized at the annual meeting of the SOCIETY in February, 1919, with an initial membership of sixty-two. From the very first meeting of the Division, when it was found that it was possible for the men engaged in the enameling industry to meet and discuss the many problems confronting them in their work, there has been a very decided spirit of coöperation and mutual helpfulness in the Enamel Division. The increase in the membership of this Division in the past few years has been phenomenal. At present there are over two hundred and fifty members, which is a far larger number than any one previous to that time surmised were at all interested in the technical aspects of enameling. The support given in the way of corporation memberships by enameling firms has been very helpful and inspiring to the Division. The impulse to technical development given by this large group of enamel technologists working together is shown by the marked increase in number and improvement in quality of papers dealing with enameling subjects, by the marked increase in individual and coöperative experimental work done in the various plants, and by the increased efficiency in the work of the individual members.

Mr. R. D. Landrum was organizing chairman of the Division and its first councillor. The annual chairmen have been Mr. John Sanders, Mr. E. P. Poste (two years) and Mr. B. T. Sweely. Mr. R. R. Danielson has been secretary of the Division since its formation. Every member

of the Division has contributed to its success, but to these gentlemen must go the credit of leadership in the formation and conduct of the affairs of the Division.

Investigation of Fish-Scaling

The establishment of an Enamel Section in the Bureau of Standards has been of material benefit to the enameling industry and particularly to the work of the Enamel Division of the SOCIETY. It has furnished a well-equipped laboratory with a staff of high-grade research men to do the laboratory work necessary in connection with the coöperative investigations being carried on by the Enamel Division. The most noteworthy of the researches conducted up to the present was the coöperative investigation of fish-scaling in enamels on steel conducted by the Enamel Division and the Bureau. In breadth of scope, accuracy of execution, number of individuals and firms coöperating, and potential value of results, this is without doubt the finest piece of research work ever conducted in the field of enamel technology. Many firms, laboratories and individuals coöperated in this investigation but the credit for carrying it to such a successful conclusion must go to R. R. Danielson, W. H. Souder and their co-laborers in the Bureau of Standards.

Conclusion

There are many phases of the development of the enameling industry which it has not been possible to discuss. There are many men who have been active in promoting the development of enameling technology who have not been mentioned. We all know these men and in our thoughts of them give full credit. If there are any inaccuracies in my statements they are absolutely open to correction for I will be only too glad to rectify any errors.

It was St. Paul, I believe, who said, "I am a citizen of no mean city." In the same spirit we who are engaged in the enameling industry may say we are members of no mean profession. The enameling industry of this country is a big business, a useful business and one which requires ability, alertness and energy. It is a business in which any of us may be proud to say we have a part.

METAL & THERMIT CORPORATION
120 BROADWAY, NEW YORK, N. Y.

TWENTY-FIVE YEARS PROGRESS IN THE GLASS INDUSTRY

BY E. W. TILLOTSON¹

The Arts of Life supply instances of periods when the Genius of Invention has been scarcely manifested; and others, when its progress has had accelerated velocity; among which latter the present seems most interesting.—*Simeon Shaw*, 1837.

¹ Assistant Director of the Mellon Institute of Industrial Research of the University of Pittsburgh, Pittsburgh, Pa.

In a recent paper¹ a vivid story of the glass industry of the latter part of the last century was presented by one who has been in intimate contact with all phases of the industry. That story was interrupted at a period about twenty-five years ago and so this account is, in a sense, a continuation of it, although the author has not the advantage of long personal contact. Twenty-five years ago the use of natural gas had become well established as a fuel in the glass factory. However, the design of furnaces for the application of this fuel had not been worked out and in general the "deep eye" pot furnace was in common use. The tank furnace had been introduced by Mr. James A. Chambers about ten years before and this type of furnace was coming into favor in the window glass factories. The machines for the handling of materials and for the fabrication of glassware with which we are now familiar were for the most part undreamed of in the glass factory. At most, they were, twenty-five years ago, in the early stages of development and were looked upon with suspicion by the majority of glass workers. In the application of chemistry to the glassmaking processes the greater part of the advancement both in this country and abroad has taken place during the period under consideration. The making of "lime flint" glass of good color had been accomplished over 50 years ago by using sodium bicarbonate in the place of the LeBlanc soda ash which produced an off-color glass, but with the advent of the Solvay process soda ash the use of the expensive bicarbonate became unnecessary and by 1900 "lime flint" of good quality was being melted in tanks.

Growth of the Industry

During this period the glass industry as a whole has enjoyed a normal expansion, particularly since natural gas became available. This growth may be shown conveniently by the quantities of sand consumed in the industry, since sand constitutes fairly constantly 70 to 75% of the substance of the glass.

Year	Short tons	Value
1902	943,135	807,797
1905	1,060,334	1,107,730
1910	1,461,089	1,516,711
1915	1,884,044	1,606,640
1916	2,018,317	1,957,797
1917	1,942,675	2,685,014
1918	2,172,887	4,209,728
1919	1,827,409	3,593,371
1920	2,165,926	4,748,690
1921	1,280,359	2,314,314

Natural gas, because of its convenience and availability did much to stabilize the glass industry by putting it on a profitable basis, and the

¹ H. L. Dixon, *Jour. Amer. Ceram. Soc.*, 4, 85 (1921).

glass manufacturer was thereby enabled to direct his attention to the development of mechanical appliances. This is illustrated best, perhaps, by the plate glass industry, which, until the advent of natural gas, had not been established permanently in spite of several attempts. Today we are witnessing the retirement of natural gas and the introduction of producer gas as the standard fuel of the glass industry. This development brings with it new problems in the design and construction of glass furnaces and leers, the solutions of which will be less difficult, perhaps, because of the experience gained with natural gas.

Development of Mechanical Appliances

Practically all the automatic and semi-automatic glass-forming machinery has been developed to its present successful commercial use in the past 25 years. The following table¹ presents some of the noteworthy advances in the glass industry.

To discuss the development of each of the great mechanical inventions and its effect on the industry would require more space than is available here; but it may be appropriate to point out that the automatic machines have increased the production per man, it is estimated, from five to ten times, and, in addition, a better quality of ware and a more uniform product are secured. Then, too, the general use of machinery has made for larger installations and more permanent buildings, and this result has necessitated the introduction of mechanical appliances for the handling of raw materials, for weighing and mixing the batch and conveying it to the furnaces, and also for conveying the glass articles from the presses to the leers. The continuous mechanically operated leer for small articles is of comparatively recent adoption.

Advances in Chemical Technology

As mentioned before, the introduction of Solvay process soda ash was a boon to the glassmaker since it did not contain the color-forming impurities which were present in the LeBlanc soda, and made possible the production of a fair quality of "crystal" glass or "lime flint" in the tank furnaces. Of late years, the use of selenium in the place of manganese dioxide as a "decolorizer" has improved materially the "color of glass produced in tanks and has insured a more uniform color from day to day."

Among the new types of glassware developed recently should be mentioned the translucent alabaster glasses which have found a wide use for illumination purposes. While this type of glass is relatively old the present day examples represent distinct advances.²

Among the outstanding developments in new glasses the most important

¹ Tillotson, *Chem. & Met. Eng.*, **23**, 461 (1920).

² See A. Silverman, "Alabaster Glass," *Jour. Amer. Céram. Soc.*, **1**, 247 (1918).

Innovation	Date	By whom introduced	Place	Comments
First glass factory in America.....	1608	.....	Jamestown, Va.	For the manufacture of beads and bottles.
Pressed glass.....	1827	A carpenter, name unknown	Sandwich, Mass.	The Boston & Sandwich Glass Co., Deming Jarves, mgr.
First plate-glass factory in America.....	1857	.....	Williamsburg, N. Y.	Failed by reason of competition from France and Belgium.
Lime-flint glass.....	1864	William Leighton, Sr.	Wheeling, W. Va.	This invention nearly extinguished the old flint industry.
First regenerative pot furnace.....	1865	James B. Lyon	Pittsburgh, Pa.	Built at the O'Hara Glass Works, for use with producer gas.
First continuous tank in America.....	1879	Poughkeepsie Glass Works	Poughkeepsie, N. Y.	For the manufacture of bottles.
First use of natural gas in melting glass.	1883	Bradford Window Glass Co.	Bradford, Pa.	In 1884, gas was used for melting flint glass in the Riverside Glass Works, Wellsburg, W. Va.
Prepressed blank.....	1882	Philip Arbogast	Pittsburgh, Pa.	An important step in the development of the automatic bottle machines.
Continuous leer for window glass.....	1882	Cleon Tondeur	Dunhamville, N. Y.	Fox & Sons Window Glass Co. (the "rod" leer).
Continuous tank for window glass.....	1884	United Glass Works	Streator, Ill.	.....
Wire glass.....	1892	Frank Schuman	Tacony, Pa.	.....
Favrile glass.....	1892	The Tiffany Furnaces	Corona, L. I.	.....
Selenium ruby glass.....	1894	Nicholas Kopp	Pittsburgh, Pa.	.....
Flint "lime" glass melted in tank.....	1898	Charles H. Runyon	Rochester, Pa.	Keystone Glass Co.
Continuous leer for plate glass.....	1898	Marsh Plate Glass Works	Walton, Pa.	.....
Fire polishing cut glass blanks.....	1899	Michael J. Owens	Toledo, Ohio	.....
Automatic bottle machine.....	1899	Michael J. Owens	Toledo, Ohio	.....
Machine drawn window glass.....	1900	John J. Lubbers	Pittsburgh, Pa.	The American Window Glass Machine.
Machine drawn sheet glass.....	1903	Irving W. Colburn	Franklin, Pa.	The Libbey Owens Sheet Glass Machine.
Flowing device.....	1903	Homer Brooke	Jersey City, N. J.	Used in connection with automatic machines.
Continuous leer for flint glass.....	1908	Maryland Glass Corporation	Baltimore, Md.	The intermittent pan leer had been in use for fifty years.
Low expansion glasses.....	1915	E. C. Sullivan & W. C. Taylor	Corning, N. Y.	Pyrex glass.
Hartford-Fairmont feeder.....	1915	Karl J. Peiler	Fairmont, W. Va.	For use with automatic machines
Automatic tube machine.....	1916	Edward Danner	Toledo, Ohio	.....
Automatic bulb machine.....	1917	August Kadow	Toledo, Ohio	The Westlake machine producing bulbs for incandescent lights.

is perhaps the introduction for a variety of purposes of the remarkable low-expansion glasses. The resistance of some of these glasses to chemical attack, in combination with their high resistance to sudden changes of temperature, renders them particularly suitable for laboratory apparatus and also for the more familiar use in the home for baking dishes. One of these glasses at least has proved to be successful as a teapot and an all-glass coffee percolator is to be made commercially available soon. These specific examples are suggestive, at least, of the possibilities in the development of new glasses and in the extension of the uses of glass. Other important advances in glasses for specific purposes are recorded in the patent literature.¹

This *Journal* contains fairly complete reports of one of the most remarkable developments in the glass industry; namely, the establishment of the manufacture of optical glass in this country. The work carried out in that period teems with much of fundamental value to the whole glass industry. For example, the principles underlying the annealing of glass which were developed mathematically and demonstrated practically are important, not only for the better understanding of glass, but also for designing correctly the leers in which the annealing is accomplished. Of direct interest to every glass manufacturer, also, is the study of "stones," "devitrification" and other defects in glass, the methods of recognizing their cause, and the means of their prevention. In addition, the investigations in connection with optical glass have led to a number of research inquiries which may appear on the surface to be of only scientific interest, but which, after interpretation in the terms of practice, will be found to be of direct practical value.

The recent past, in the glass industry, has been one of glorious accomplishment, the present is a period of undiminished progress, and the future is promising of still greater attainments.

GLASS POTS AND TANK BLOCKS

BY A. V. BLEININGER

Practical experience has shown that for the making of the principal glass house refractories, pots and tank blocks, the combination of the plas-

¹ See, in particular, the following U. S. Patents:

1,127,042	1,151,911	1,411,133
1,127,044	1,295,298	1,411,134
1,225,147	1,304,622	1,169,571
1,226,088	1,292,147	1,394,296
1,233,486	1,292,148	1,239,051
1,431,166	1,305,793	1,365,797
1,192,474	1,305,794	1,217,956
1,304,623	1,369,988	1,278,164

tic Missouri clays with materials of the Gross Almerode type has given the most satisfactory results. On the other hand, it has been found possible to produce such refractories of excellent quality entirely from domestic materials. But it is evident that the conditions of use have a profound influence upon the results obtained. It is not immaterial whether the glass house accessories are properly pre-fired or not, nor how they may be treated in the furnace.

We know now that the Gross Almerode clay owes its valuable properties to its low drying and firing shrinkage, its high bonding power and its constancy in volume upon long continued heating. On the other hand it is not entirely free from certain defects such as its tendency to spall under conditions of sudden heating and cooling. All of these properties are associated with its high content of finely divided quartz. It has been found possible to reproduce these properties in a large measure by the use of natural siliceous clays from American sources and the introduction of finely ground quartz.

While good results are being obtained with the present type of clay refractories for this purpose it is a question whether this will continue in view of the fact that furnace temperatures are being pushed upward. It is possible that we may have to create new types of compositions.

In the molding processes of pots and blocks no decided changes have been made during the past 25 years but a start has been made in the use of the casting process and it is claimed that blocks can be made successfully by machinery. The primitive methods of mixing the materials and the tramping of the clay are being rapidly replaced by mechanical operation. A beginning has been made in the use of improved drying systems. Again, more attention is being paid to the firing of the blocks in the kilns and of pots in the arches. In one instance the tunnel kiln is being used. In a number of plants improved arches have been built and the necessity of proper burning is being realized. There is, however, still much room for improvement in the use of higher temperatures for the pre-firing.

There is need also of improved methods of handling the pots and blocks and other accessories, especially in getting them to the furnace or tank. Draw pots as used in window glass making are too often subjected to extremely severe use through improper heating and irregular turning. The sooner it is realized that the careful handling and use of the glass house refractories are an important part of plant operation and not an annoying detail the more profitable it will be for the business.

Special pot compositions have been brought into use in connection with general glass making as well as in the production of optical and special glasses. Thus Scholes' feldspathic and the porcelain composition of the Bureau of Standards might be mentioned in which the body consists of kaolin, ball clay, flint and feldspar, mixed with whiteware grog, and fired to

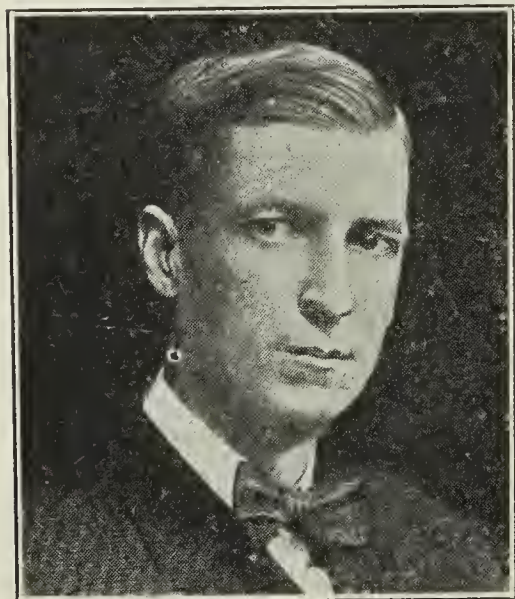
vitrification. Special compositions are used also for the accessories of glass presses provided with automatic feeders.

Summing up we may say that while progress in this branch of the ceramic industry is necessarily slow owing to the long time required to learn the results of any change made, definite advance must be recorded which we may expect to be accelerated as we shall learn more about the facts of glass attack and the changes caused by high temperatures in the structure of these refractories.

IMPORTANT DEVELOPMENTS IN THE GLASS INDUSTRY

By A. W. KIMES

To properly tell of the advancement and improvements in the art of glass manufacture, that have been made within the past 25 years would require an issue of the *Journal of the American Ceramic Society* larger in size than this special edition. To give due credit to the gentlemen who

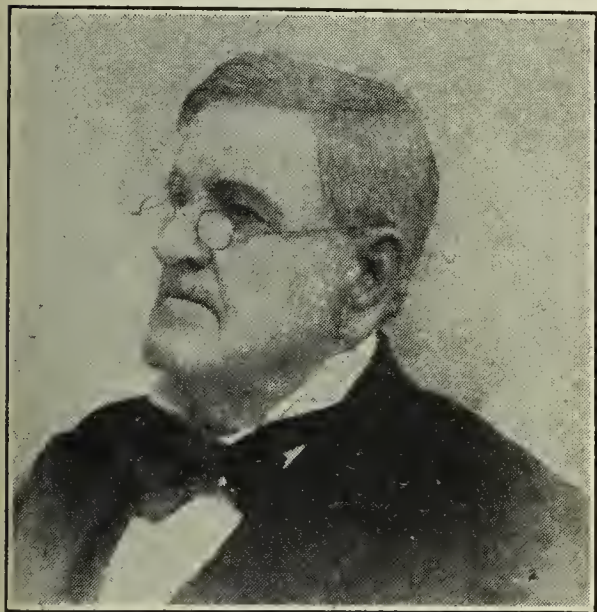


J. R. JOHNSTON, most prominent man engaged in manufacture and distribution of hand-made window glass.

so earnestly labored in an effort to modernize the production of glass and glassware would require greater space than is available. During the period mentioned the process of manufacturing all kinds of glass and glassware, with but one or two exceptions, has been advanced from the hand to the automatic method. Unlimited credit is due scores of men who have taken a prominent part in giving to the glass industry some of the most wonderful automatic machinery used in the production of hundreds of different kinds of glass articles and placing the development attained in the glass business equal to that achieved in any other industry.

Within the past two and one-half decades the Owens bottle machine has been perfected from what was then claimed to be an impossibility to one of the greatest mechanical marvels of the age. Early in its development but little encouragement was given to its promoters. They often were confronted with the statement, "it might make certain ware, but on other lines it was destined to fail." However, today sees this wonderful machine producing in range from the tiniest bottle at the rate of almost 200 a minute to the five-gallon water bottle, entirely automatically made, at the rate of six per minute. Articles produced within these extreme limits include such as the quart fruit jar that is turned out on this same device at a speed of one each second of time.

There are scores of other machines that are automatic in their functioning and many that are semi-automatic in their operation that are commercially engaged in producing glass articles and containers in almost every imaginable size and shape. Regardless of the fact that so much



J. B. FORD, father of the plate glass industry in the United States.

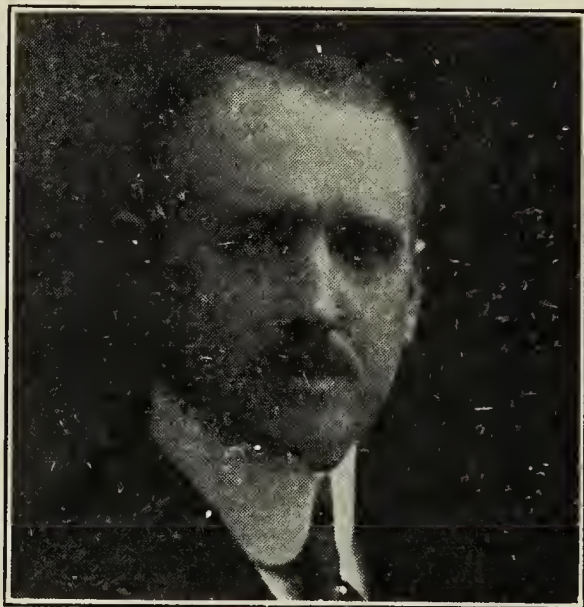
progress has been made within the above specified time, there are still great possibilities for further development.

Another automatic marvel to be found in the glass industry is the tube drawing machine generally known as the "Danner." It has been termed by some as a device that works closer to the nature of molten glass than any other machine. This problem is so difficult of solution that but few will express an authoritative opinion. It accomplishes its work in drawing glass tubing of various sizes and uniformity of wall at a rate of about 150 feet per minute, varying according to the diameter, with

such apparent ease that the observer is astounded at its efficiency.

Perhaps one of the most important advancements taking place in the glass industry is that of the introduction and perfection of glass-feeding and flowing devices, which by their various methods transfer the molten glass from tanks to different types of glassworking machinery. Many of these inventions are highly successful and have accomplished objectives almost beyond anticipation.

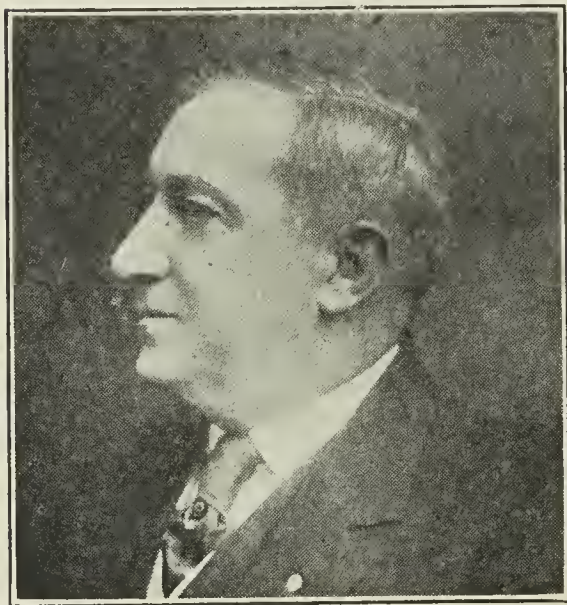
There are a number of other machines busily engaged in the production of scientific and other kinds of glassware that are no less wonderful but equally meritorious in achievement in their respective lines, that cannot be described here by reason of the necessity of their operators' desire to keep their points of superiority concealed lest they be used in an unjustifiable manner.



CHARLES W. BROWN, president of the Pittsburgh Plate Glass Co.

Passing to the flat glass industry the advancement in this line has been no less remarkable. In this branch of the trade there is to be found the American window glass cylinder-drawing machine which has attained such a high state of efficiency that 12 machines attached to one tank are capable of drawing cylinders 518 inches in length after the shoulder and lower ragged edge have been removed and

of any desired diameter up to 33 inches. The glass drawn varies in thickness from 32 sheets to the inch up to almost quarter-inch crystal glass. In this connection it is fitting to say that within the last month mam-



D. K. ALBRIGHT, manager of the Allegheny Plate Glass Company, Glassmere, Pa.

moth tanks which measure more than 140 feet in length have proven themselves to be startlingly efficient in operation, two attaining a production per machine during an entire week's operation that is most remarkable. The production of one of these tanks equalled 91.4 fifty-foot boxes in each eight-hour turn, and maintained that speed one entire week. A duplicate tank in another factory exceeded this record by drawing 92.1 fifty-foot boxes of glass per turn. The quality of this large production is equal to that produced anywhere.

Another creation that has proven to be a commercial success, within the period under discussion, is that known as the Libbey-Owens sheet glass method. By this process the glass is melted in a tank and by skilfully devised methods continuous sheets of glass are drawn in various thicknesses and ranging up to more than 80 inches in width. This is another mechanical wonder to be found within the scope of the glass industry.

Numerous experiments have been made to perfect different machines that will draw flat sheets perpendicularly from the tank, or from a compartment attached thereto. These machines have been developed to a point where their inventors claim them to be commercially successful.

A common expression heard when discussing the method of manufacturing plate glass is that there had not been any improvements made since its first introduction in America; but within the last decade this statement is entirely erroneous, as material progress has been made resulting in revolutionizing the early practice. The modern plate glass works of today are entirely unlike those in operation at the beginning of the present century.

Perhaps one of the greatest innovations successfully achieved was that

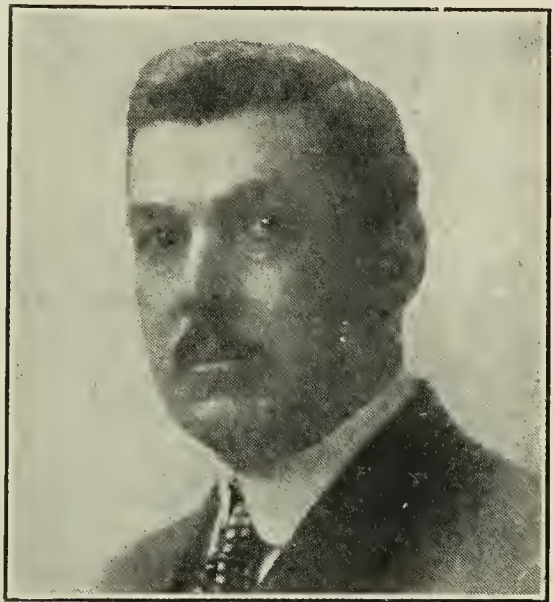


W. L. CLAUSE, chairman of Board of Directors, Pittsburgh Plate Glass Company.

of supplanting the pot furnace by the tank method of melting plate glass. Like unto many other new ideas, many predicted its ultimate failure. Rapid strides have been made in the handling of raw materials, factory operation and conveyance of the larger sheets of plate glass found in the largest display windows.

Developments in the composition of other kinds of glass and glassware have been far beyond general expectation.

We might mention among some of the greatest achievements the introduction of "Pyrex" glassware made by the Corning Glass Works, of Corning, N. Y., the "Oven Ware" of the H. C. Fry Glass Company, Rochester, Pa., and heat-resisting glass produced by other glass manufacturing companies. A new creation is that of safety, or bullet-proof glass, which generally consists of two thin sheets of glass between which is placed a composite material then subjected to predetermined heat and pressure which unites them into a solid mass and produces a glass that will withstand a severe shock or completely retard the passage of a bullet; the glass may be shattered but still retains its shape and form.



W. L. MONRO, president and general manager of the American Window Glass Co., Pittsburgh, Pa.

The foregoing outline mentions but few of the important developments that are to be found in the glass industry and it can be safely predicted that within the next quarter of a century greater strides will be realized.

PRODUCER PROGRESS DURING THE PAST QUARTER CENTURY

BY W. B. CHAPMAN

Twenty-five years ago one lone mechanical producer at the Pencoid Iron Works, designed by the then Chief Engineer of the Company, Mr. W. B. Hughes, was in daily operation proclaiming to all who came to see it that a mechanical producer could be built that would actually run and perform a large part of the heavy manual labor required for making producer gas. This original producer is still in operation.

For over a decade no further advance was made and no one could be induced to follow the lead of the Pencoid people. Then, two years before the Hughes patents expired, the Harrisburg Pipe Bending Company listened to Mr. Hughes importuning and ventured an installation, the success of which led the Pennsylvania Steel Company to adopt the new

mechanical producer for the exacting duty imposed by their large open hearth furnaces. The installation was a success from the start, and from that time on the progress of the mechanical producer was rapid. We now seldom hear of any one installing old-fashioned hand-operated gas producers, and the old gas house adage that "there is usually more gas in the poker than in the coal" is rarely heard.

Probably 1,000 tons of coal and 1,000 days of labor are now saved every day in the United States because of the contribution of pioneer work done on the mechanical gas producer by W. B. Hughes. This is also true

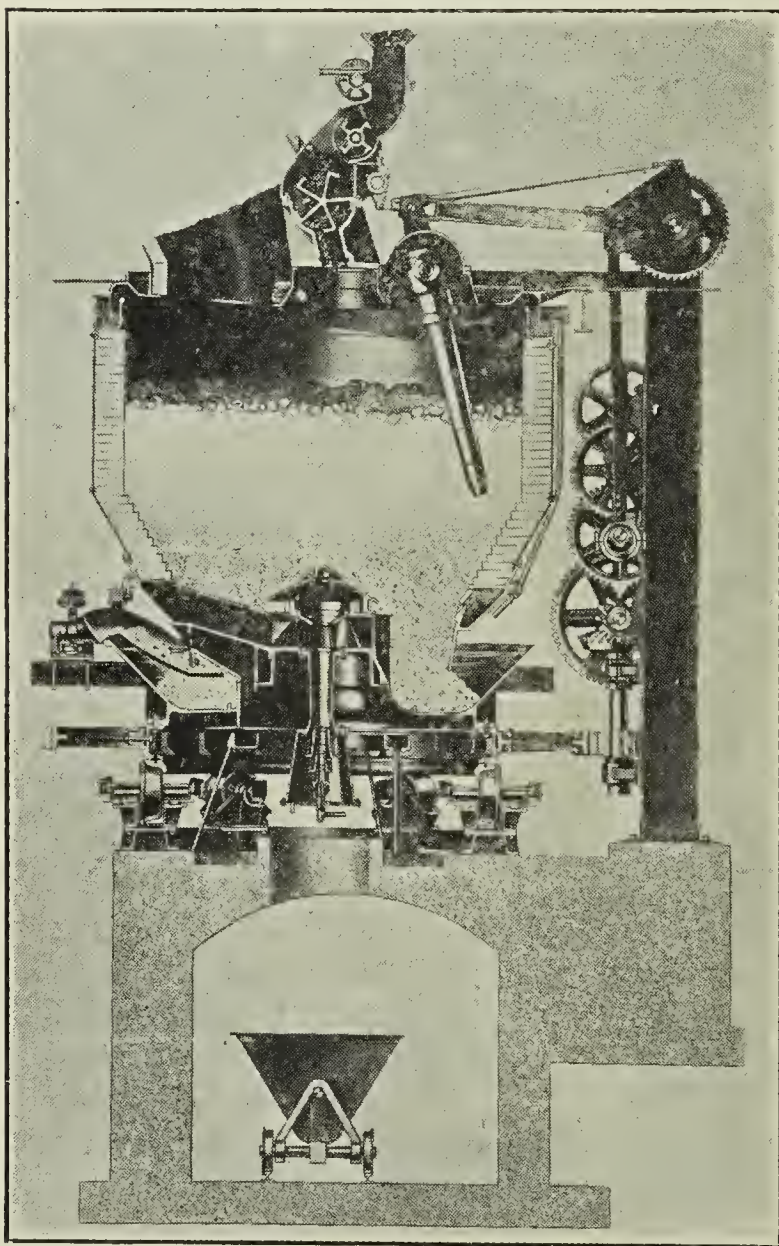


FIG. 1.—Hughes gas producer.

to a considerable extent of the other two large producer manufacturers that followed Mr. Hughes' lead, *i. e.*, the Morgan Construction Company, the Chapman Engineering Co., and later R. D. Wood and Company added its contribution to the producer gas art. We now have four different types of mechanical producer on the market, each doing good work and each having a distinct individuality of its own.

Before the advent of the mechanical producer, two automatic coal feeds, the Bildt and the George, were developed and extensively exploited.

they did not make much of a contribution toward solving the problems for which they were designed and ultimately were abandoned.

Meanwhile as the Hughes producer was gaining in favor, several unsuccessful efforts were

made to place on the American market producers of European design having a revolving ash pan with a large non-circular or irregular shaped blast-box which projected well up into the producer and slowly revolved with the ash pan, thus crushing and forcing out the ashes. The writer spent many months in trying to handle various American coals with this type of European producer. It did excellent work in so far as it went. It crushed the ashes and removed them in a way that left little to be

desired but the agitation did not reach far enough up into the fire where the clinkers were being made. Moreover, there was no agitation at all in the middle and upper portion of the fire-bed. The European type may work satisfactorily with certain free-burning European coals (though we doubt it) but it will never answer for American coals that make trouble not only in the bottom of the fire-bed but in the middle and top as well.

So attention in America was concentrated on the stirring or agitating of the middle and upper part of the fire-bed, and for the time being the under portion was neglected. The Chapman Engineering Company tried agitating the surface and at the same time twisting the upper half of the fire-bed over the lower half upon which it rested. This was done to twist out the blow holes and produce agitation without requiring an agitating member. But in the larger sizes there was too much agitation near the walls; so the twisting method of solving the problem had to be abandoned.

The Morgan people next brought out a successful producer in which surface agitation alone was featured, it being claimed that anything other than surface agitation was detrimental to good gas making. This Morgan Producer, equipped as it is with automatic feed, swinging U-tube and mechanical ash re-

moval, is one of the most popular in the steel trade. It was the first successful producer to appear after the Hughes.

About the same time appeared the Wood Producer (1915) with its two vertical stirring fingers. The two stirrers give a larger capacity but make it impossible to operate the producer at less than half load. In this producer the ashes are removed mechanically every few hours instead of only once or twice a day as is the case with the Hughes and Morgan. Some remarkable results have been obtained with the Wood Producer, and its twin the Camden. This type is quite popular in the glass trade.

In 1916, the first Chapman Agitator was built. It was tried first in a zinc plant using anthracite coal because it was thought that it might not

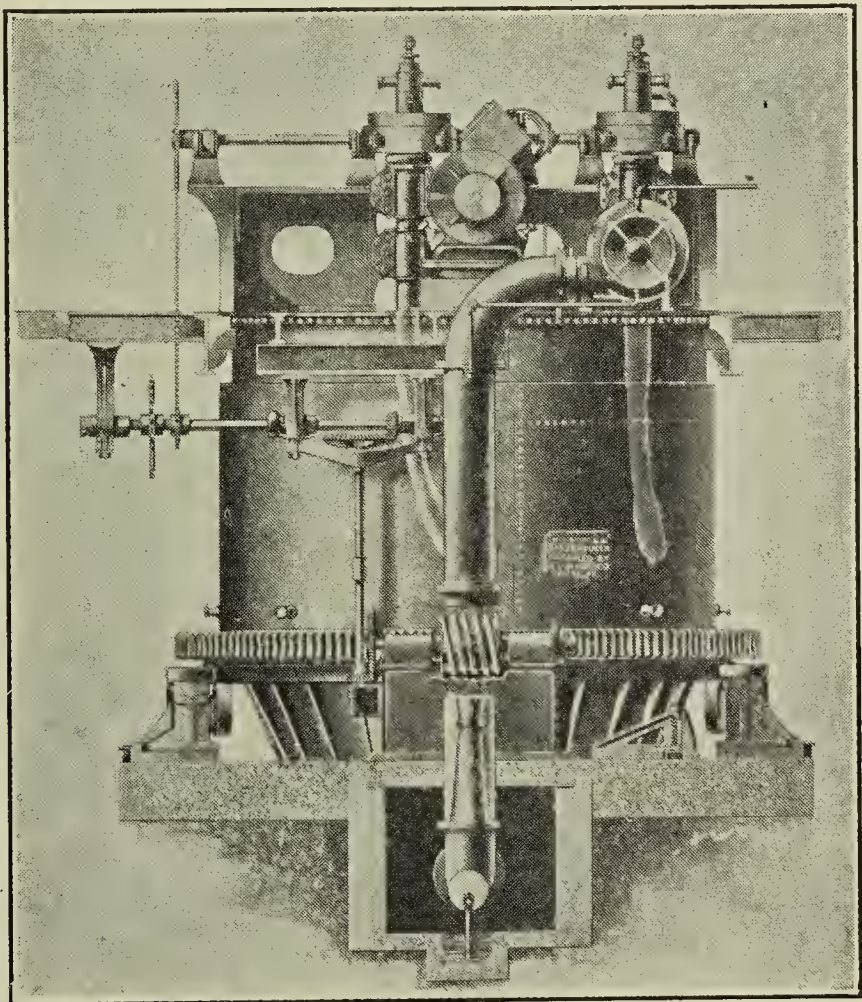


FIG. 2.—R. D. Wood gas producer.

work on bituminous coal. It did not do enough good on fine anthracite coal to be worth while, so it was rebuilt and moved to a window glass factory in Indiana for another trial. Here it laid around on the ground for many weeks before being given a trial, as it was said that the agitator would never rise and fall automatically with the varying height of the fire-bed. When finally it was tested it worked right from the start and no fundamental changes have had to be made in the six years that have elapsed since then.

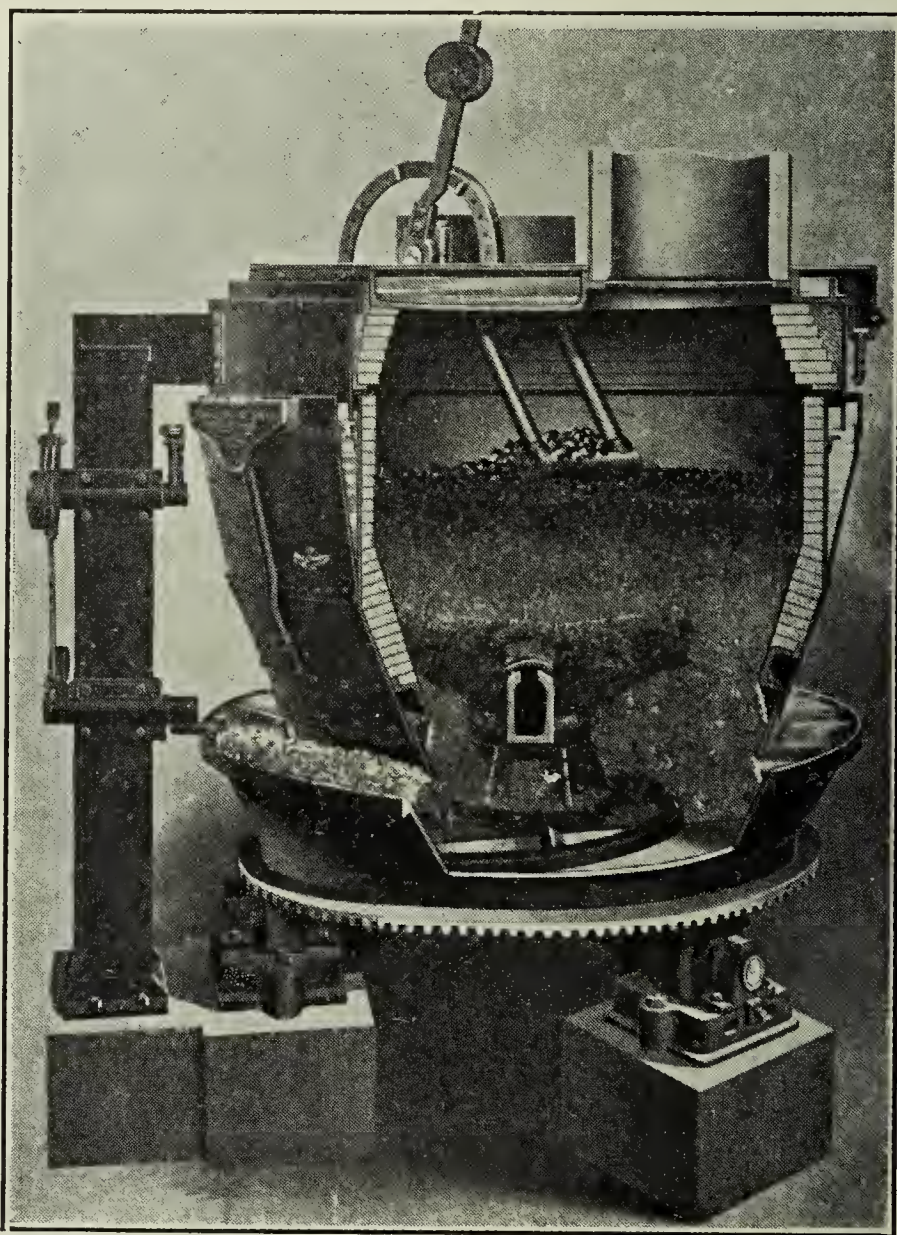


FIG. 3.—The Morgan producer gas machine and Dyblie reversing valves.

In making producer gas there are three steps:

1. Feeding and spreading the fuel
2. Agitating the fire-bed
3. Removing the ashes

In all of the four types of mechanical producers on the market all three of these steps are performed mechanically, although in no two of them is this accomplished in quite the same way. All but the Chapman have a revolving wall carrying a revolving fire-bed. A revolving bed is required

by the eccentric location of the automatic feed and is also required by the eccentric location of the agitating members used. In the Chapman the agitator is centrally located and the fuel is fed centrally; hence it is not necessary to revolve the heavier producer walls and fire-bed.

In the Hughes and Morgan method producers the method of ash removal employed makes it necessary to revolve the ash pan. In the Wood and Chapman designs, the ash pan is stationary and hence made of concrete. In the Hughes and Morgan producers the top is of metal and water-cooled, while in the Wood and Chapman type the top is of fire brick.

The Morgan swinging U-tube and the Chapman Agitator operate automatically in the surface of the fire-bed, in contra-distinction to the vertical stirring fingers of the Hughes and Wood types, which have to reach to within

a few inches of the bottom of the fire-bed for best results. Those producers in which the height of the agitating member automatically changes in height are especially flexible as to capacity. They will give about as good results at $\frac{1}{10}$ capacity as at maximum.

The Chapman Agitator has been tried many times without the agitating fingers and in spite of the fact that the cross arm passes through the surface of the fire-bed three times as frequently as in other types, it has been found in every case that the stirring fingers add 25% to 33% to the effectiveness of the agitator. There are some 350 of these agitators in service in the glass industry.

But most of these differences in producer design are more apparent than real. The results actually obtained do not differ as widely as one might expect. In all four types of mechanical producers it is not difficult to gasify twice as much, and sometimes three times as much fuel as in the old-style hand-operated producers; and at the same time a much better

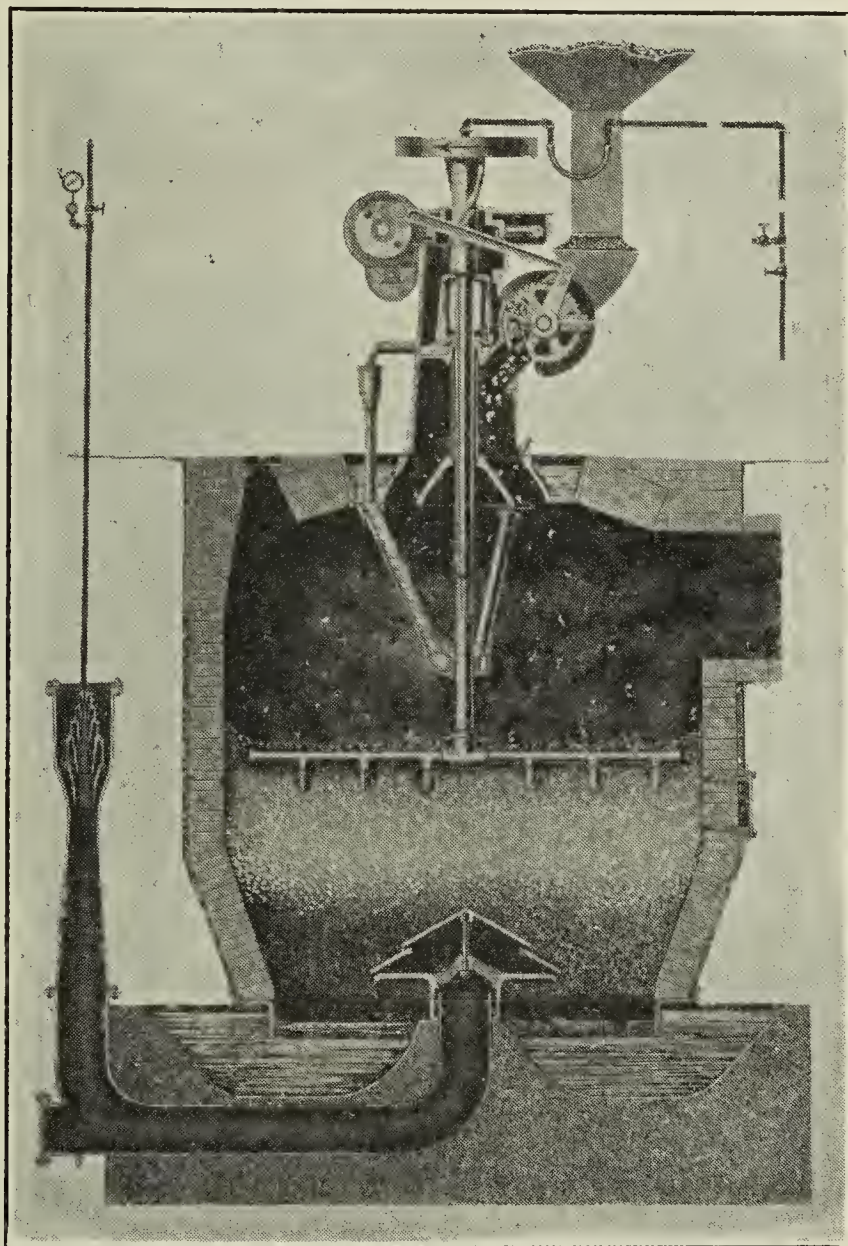


FIG. 4.—Chapman floating agitator producer.

gas can be made. It is easier to make a 150 B.t.u. gas in a mechanical producer than a 120 B.t.u. in a hand-operated one.

An installation of mechanical producers usually saves about 25% of the fuel, but it rarely happens that this saving of 25% is effected in the producer itself. The greater portion of the saving is brought about in the furnace due to the richer gas which makes possible a higher initial flame temperature and due also to the more uniform quality and quantity of the gas which makes it possible to adjust the air very closely to the needs of the furnace. Before the advent of the mechanical producer it was common practice for each furnace to waste from 10 to 30% of the fuel because it was impossible to keep the air adjusted to suit the fluctuations in the quality and quantity of the producer gas.

The new (1921) Chapman Continuous Producer attempts to combine the advantages of the European method of continuous (instead of intermittent) ash removal with the features of the Chapman Agitator. The ash beam that withdraws the ashes from this producer moves continuously at any desired speed from $1\frac{1}{2}$ revolution in an hour to one revolution a day. It thus makes a continuous (although slight) agitation of the ashes upon which the fire-bed rests. This is a distinct departure in American gas producer practice and its effect is being watched with interest. Personal attention and hand labor are reduced to a minimum.

About 10 years ago a number of leading glass makers—possibly a dozen in all—put in installations for making clean producer gas. It was erroneously supposed that if natural gas could no longer be had the next best thing would be washed producer gas—especially for the leers. However, it was learned from experience that a clean gas plant costs about twice as much to build and operate as a raw gas plant. As a result most of the installations have been abandoned. It is now possible to buy a good muffle leer that does not require clean gas.

The present trend in gas producer practice is toward simplification, labor saving, automatic regulation of gas pressure and of steam and air mixture. There is also a trend toward better methods of flue cleaning.

THE CHAPMAN ENGINEERING COMPANY
NEW YORK CITY

RECUPERATIVE FURNACES FOR THE GLASS INDUSTRY

BY W. B. CHAPMAN

During the past twenty-five years many improvements have been made in the design of glass furnaces. Tanks have been made larger, more efficient, more easily controlled, and less subject to excessive wear; leers have been perfected of the muffle type that permit the use of raw producer gas without risk of discoloration; but perhaps the most distinct advance in furnace design has been the perfection of the recuperator and its application to glass furnaces.

The recuperative furnace, because of its potential possibilities for better control of operation and economy of fuel, has long attracted the interest of glass manufacturers. But until the past decade the difficulties encountered in practical construction and operation have appeared to be insurmountable. Now that a simple and practical solution has been found for these difficulties the recuperative type of furnace is fast gaining

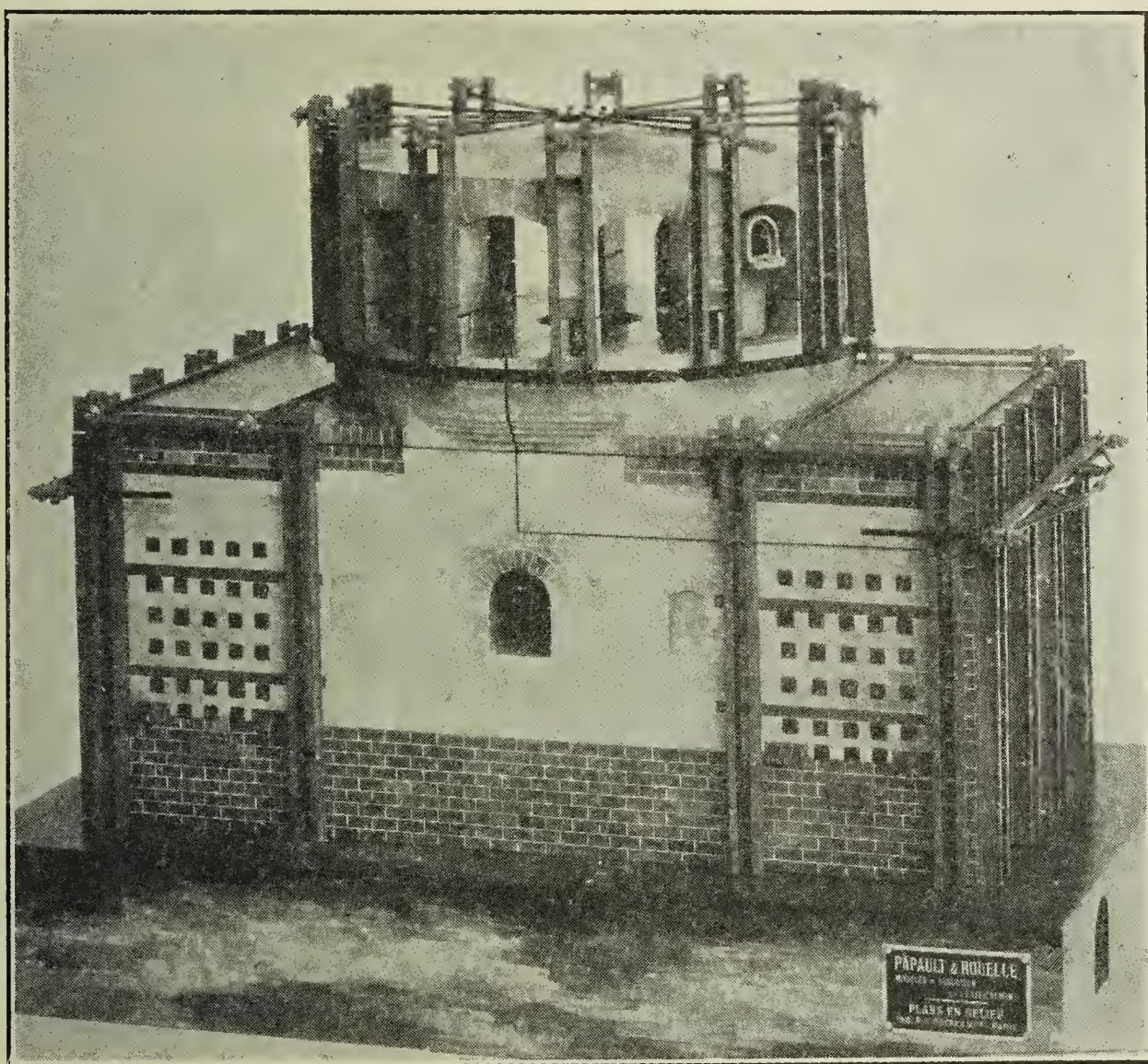


FIG. 1.—Model of Chapman-Stein closed pot recuperative furnace.

in favor. Recuperators of the Stein type are being used with marked success not only in closed pot furnaces but in small tank furnaces, day tanks and various kinds of work tanks.

During the War when coal was \$75 a ton in Paris the MM. Houdaille & Truquet of that city installed the first Stein recuperator to be used in the glass industry. It saved half the fuel. This plant today with some half dozen duplicates of the original furnace is the mecca of American glass manufacturers who visit Paris. Many of the same type are now to be seen in various parts of Europe and one has been in operation a year and a half in this country at the Imperial Glass Company in Bellaire, Ohio.

At the Bellaire plant, since their recuperative furnace was installed,

the fuel per day has been reduced about 20% and at the same time the output per day has been increased about 35% as compared with their regenerative (reversing) furnaces of the same size. There is also a considerable saving in pot breakage, for due to the even distribution of heat the pots last fully twice as long as formerly. After a year and a half of operation the furnace is just as efficient as when first installed.

The accompanying illustration is of a wooden model of a similar furnace showing one of the pots in position. There is a single eye in the center of the furnace. The gas and preheated air mix in this eye a few feet below the hearth. The flames pass from the center of the furnace out and down

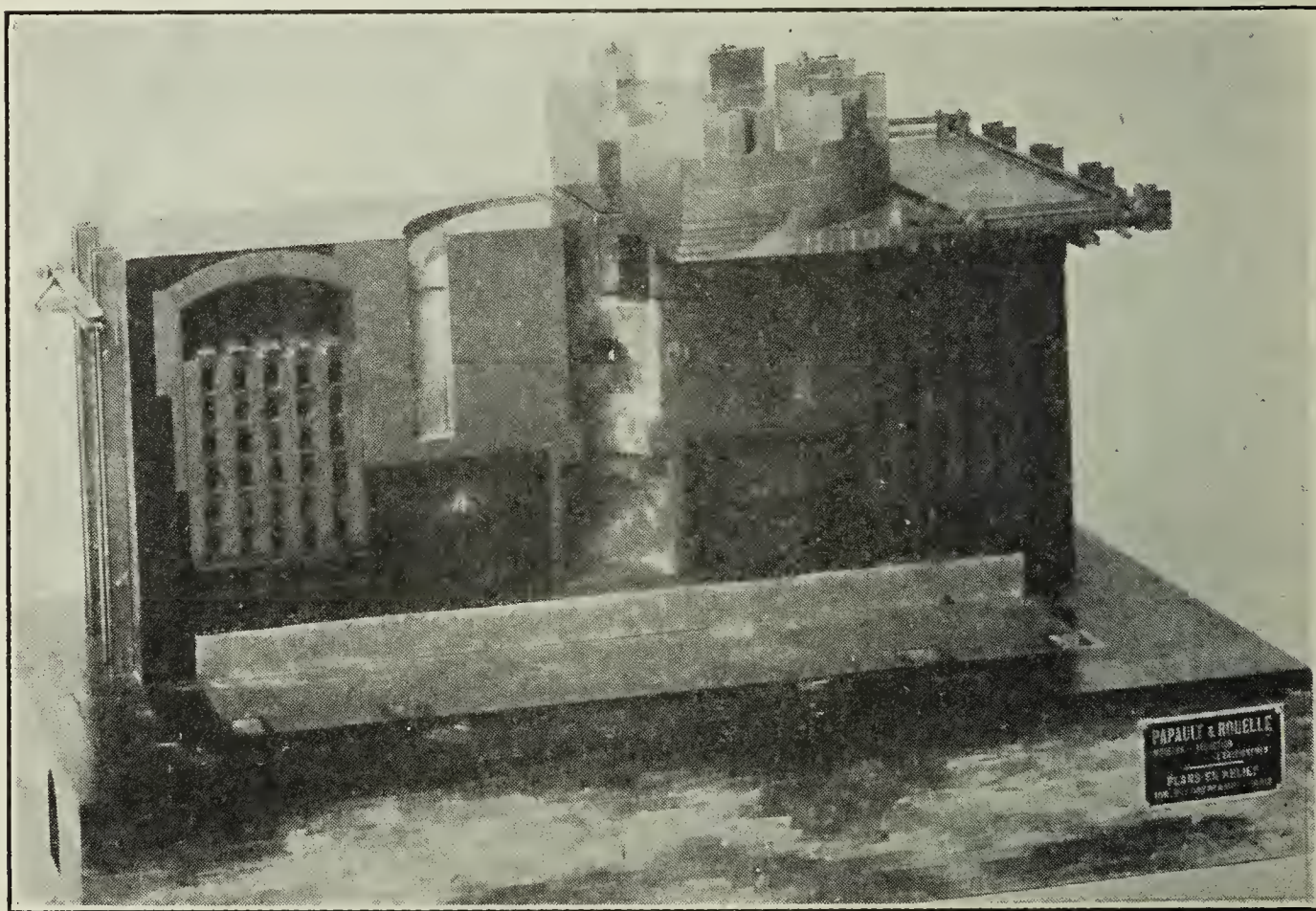


FIG. 2.—Chapman-Stein Furnace

into the off-take ports one of which is located near the base of each of the columns. As there is but one outlet into each column the pots may be set in such a way as to force the hot gases to pass around the fronts of the pots before reaching the outlet, thus bathing the pots in an even temperature of rapidly moving gases—a condition necessary for large output and long life for the pots.

The temperature of the spent gases as they enter the hollow columns and pass downward to the recuperators is about 2500°F, although it is possible to obtain as high as 2600° at this point. The air is preheated to 1900°F, which is probably about 400°F less than the temperature of the spent gases as they enter the recuperator chambers. The spent gases as they go to the stack are about 800°F.

This furnace holds 14 pots each yielding a little over a ton of finished glass. It was formerly of the regenerative type, but was rebuilt a year and a half ago and provided with Chapman-Stein recuperators.

Formerly the capacity was 40 pots a week ending at noon on Saturday. The capacity is now well over 50 pots, and 56 pots can be obtained whenever required. The life of the pots which was formerly under 4 months has been more than doubled. Although the recuperators have been heating the air to 1900°F for the past year and a half and at times to 1950° they show no sign of leakage or depreciation. The fuel consumption has been reduced from 170,000 cu. ft. of natural gas per 24-hour day to 136,000 cu. ft. which makes a fuel saving of about 55% per ton of glass. This furnace ordinarily operates on producer gas but a week's run was made on natural gas so as to get an accurate comparison of fuel consumption with past records.

In connection with the heating of rotary pots used for Owens bottle machines, Stein recuperators have shown a saving of 30% of fuel as compared with the old type of recuperative furnace which usually required a fan for the air and leaked badly. They have also shown the same amount of saving as compared with regenerators used on rotary pots.

On work tanks and other types of glass furnaces these recuperators have shown savings ranging from 20% to 60% per ton of finished product. The cost of a recuperative furnace is always less than the cost of a regenerative furnace.

The distinctive feature of the Stein Recuperative Furnace is that the recuperator air ducts are vertical and have no turn or off-sets. Sufficient natural draft is thus procured through the recuperator to give a slight pressure in the furnace without requiring a blower for the air. By eliminating a fan it is possible to avoid any excessive pressure in the air ducts

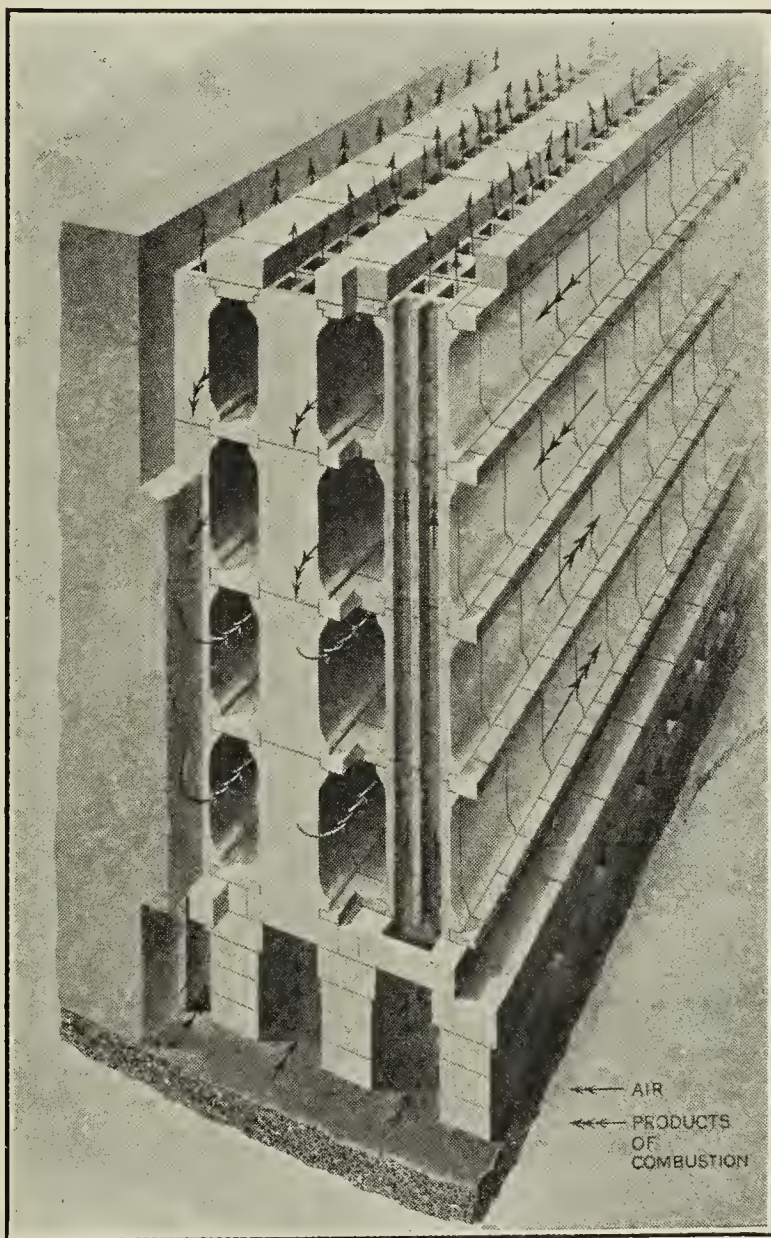


FIG. 3.—Section of Chapman-Stein recuperator.

of the recuperator. In fact the air ducts at the bottom are under a slight suction (about $\frac{1}{10}$ inch). This practically balances the suction in the spent gas passages which is about $\frac{1}{8}$ inch. There is thus practically no occasion for the air in the air passages to leak through into the spent gas passages. This, in the past, has been the chief cause for failure in the recuperative furnace, for no tile joints could be made tight enough to withstand a positive air pressure from a fan on one side of the tile and the minus pressure of the spent gases on the other.

The Stein recuperator in addition to eliminating the air pressure in the tile reduces the stack draft around the tile by making fewer turns and larger passageways for the spent gases. In this way it is possible to obtain an approximately balanced draft on each side of the tile. The entire recuperator is made with overlapping joints doubly closed so as to permit expansion and contraction without leakage. It is thus made practically leak-proof.

The special recuperator tile are held in place laterally by slabs that direct the flow of the spent gases and also serve to close the joints between the tile. These slabs in turn are held in place by lugs on the recuperator tile.

Each special recuperator tile is reinforced by two vertical partitions which permit the tile walls to be made only $\frac{3}{4}$ -inch thick thus making possible a very rapid heat transference. By making the vertical passages very small it is possible to heat the air much hotter as there is no room left in the center of the passage for a core of colder slower-moving air, as has been the case heretofore.

The tile are also made so as to break joints in every direction. In setting these tile, no attempt is made to produce a solid mass by using cement, so as to prevent leakage. The large amount of lap of the doubly closed joints, together with the fact that there is practically no difference in the air waste gas pressures on either side of the tile, is adequate insurance against leakage. In many cases these recuperators have had to withstand the jar from heavy trip hammers located nearby and no harm has resulted.

During the past three years 36 of the Chapman-Stein Recuperative Furnaces have been installed in the glass industry.

CHAPMAN ENGINEERING COMPANY
NEW YORK CITY

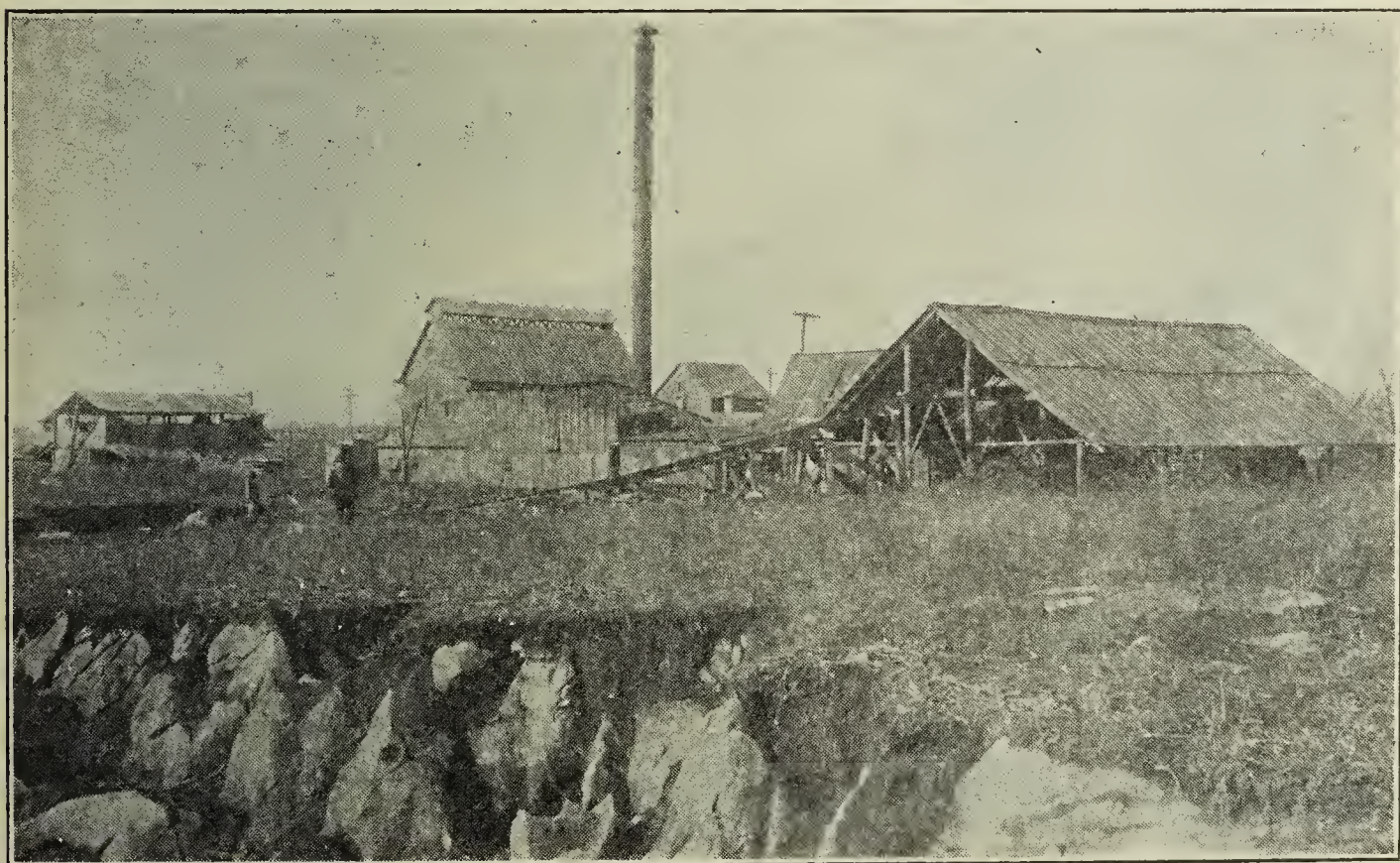
THE LOG (TWENTY-FIVE YEARS) OF PROGRESS IN THE BRICK AND TILE INDUSTRY

BY F. L. STEINHOFF

It is fortunate for the author of this article that the story of the developments that have taken place in equipment, methods and conditions incident to the manufacture of brick and tile begins at a date 25 years ago in-

stead of ending there. There would be very little to say for the quarter century antedating 25 years ago. The history of the progress of the industry is reflected to a large degree in the history of the development of the modern plant. A graphic picture of this development can best be gained by a comparison of the advertisements and texts of the modern clay journal compared to that of a trade journal 25 years back.

The subject of this article embraces a number of products and many phases incident to each. Under brick and tile we must consider face, common, paving brick, hollow building tile, drain tile, roofing tile and sewer pipe. Fire brick and terra cotta, two clay products which have made tremendous advances in the last 25 years, will not be included in this dis-



An old type of brick yard of a quarter century ago.

cussion as they are being given separate consideration by able authorities who will chronicle their history. While many processes in the manufacture of these products are common to all, there are a good many specific processes and problems in merchandising that are at great variance.

An industry is naturally influenced in its development by those factors with which it is involved. In the manufacture of brick and tile the chief factors controlling the destiny of the industry are shipping conditions, raw materials, labor, fuel, market, competition within the industry, competition from outside for the markets served by the clay industry, and management. Everyone of these factors—some of course more than others—have had some bearing upon the present status of the industry. It is not too much to say that the combined influence of these factors is almost wholly re-

sponsible for the great development in more refined machinery and equipment.

Each of the factors mentioned above is, in practically every industry, a basic cause for either progress or retrogression and each insofar as it has influenced progress in the clay industry could become the subject of a lengthy and interesting treatise. To dwell upon the progress in each of these factors would therefore require many volumes and a short article such as this is entirely inadequate to provide more than just an outline



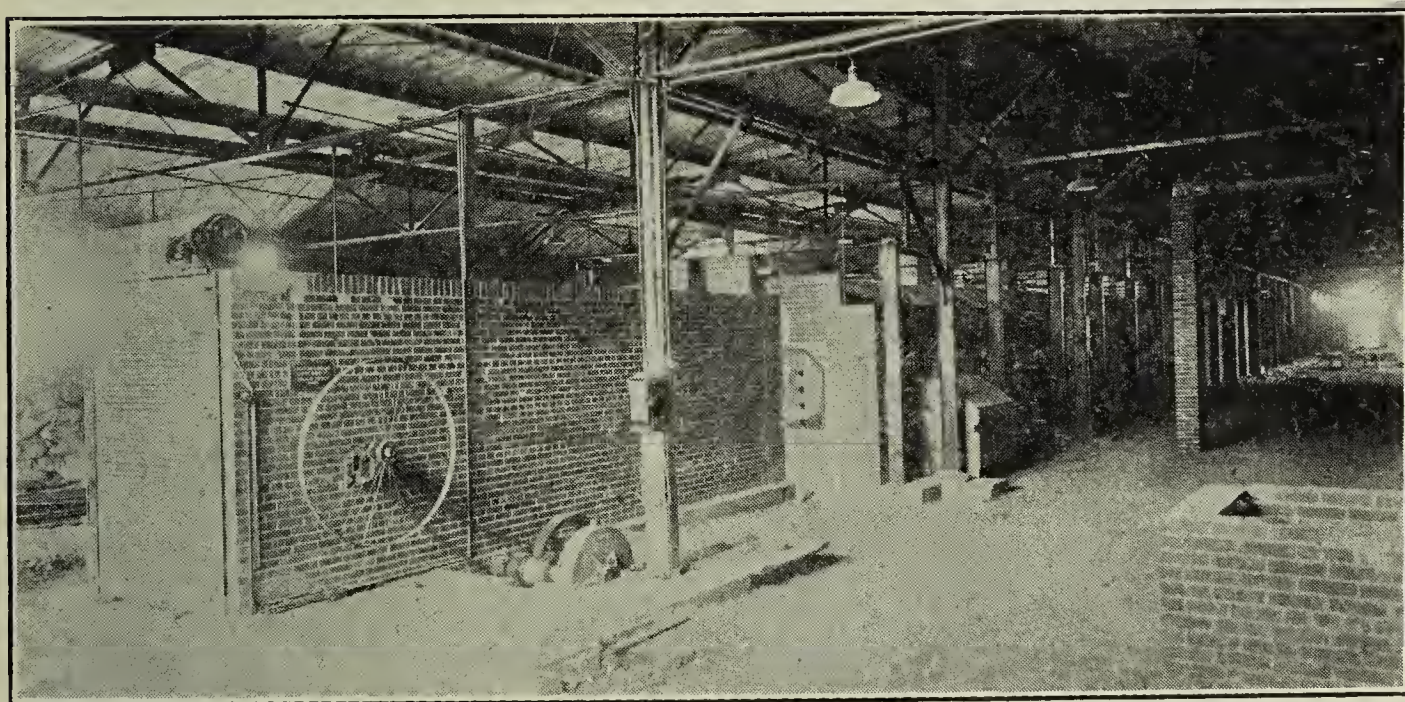
First developments in brick setting machines.

of the history of development. It is obvious that only some of the high spots can be touched and these only very briefly. No attempt is therefore being made in this article to cover each single factor in all of its phases.

Unlike most industries the plane of development in the brick and tile industry has not been uniform. For instance, there is a greater disparity in the clay industry than there is in the steel, textile or rubber business, between the most primitive and inefficient plants now in operation and the

factory that is replete with the latest and most efficient equipment and methods. Why such a condition can exist is at once made evident when it is appreciated that the products are extremely heavy and very low priced per unit of weight. This makes freight rates such a considerable part of the cost that a limitation is put upon wide distribution and the business practically localized. Therefore a manufacturer with crude and inefficient methods can often supply the needs of his community cheaper than a modern manufacturer who must ship some distance. National distribution as in the case of safety razors, clothing, rubber tires, food products, automobiles and the like is unusual rather than the rule in the clay industry.

It is truly astounding what large effect the shipping rates have had upon brick and tile manufacturers, not only in the development of the plants as to their production methods but also as to their markets as well. The



Dressler tunnel kiln at Bradford (Pa.) Brick and Tile Co.

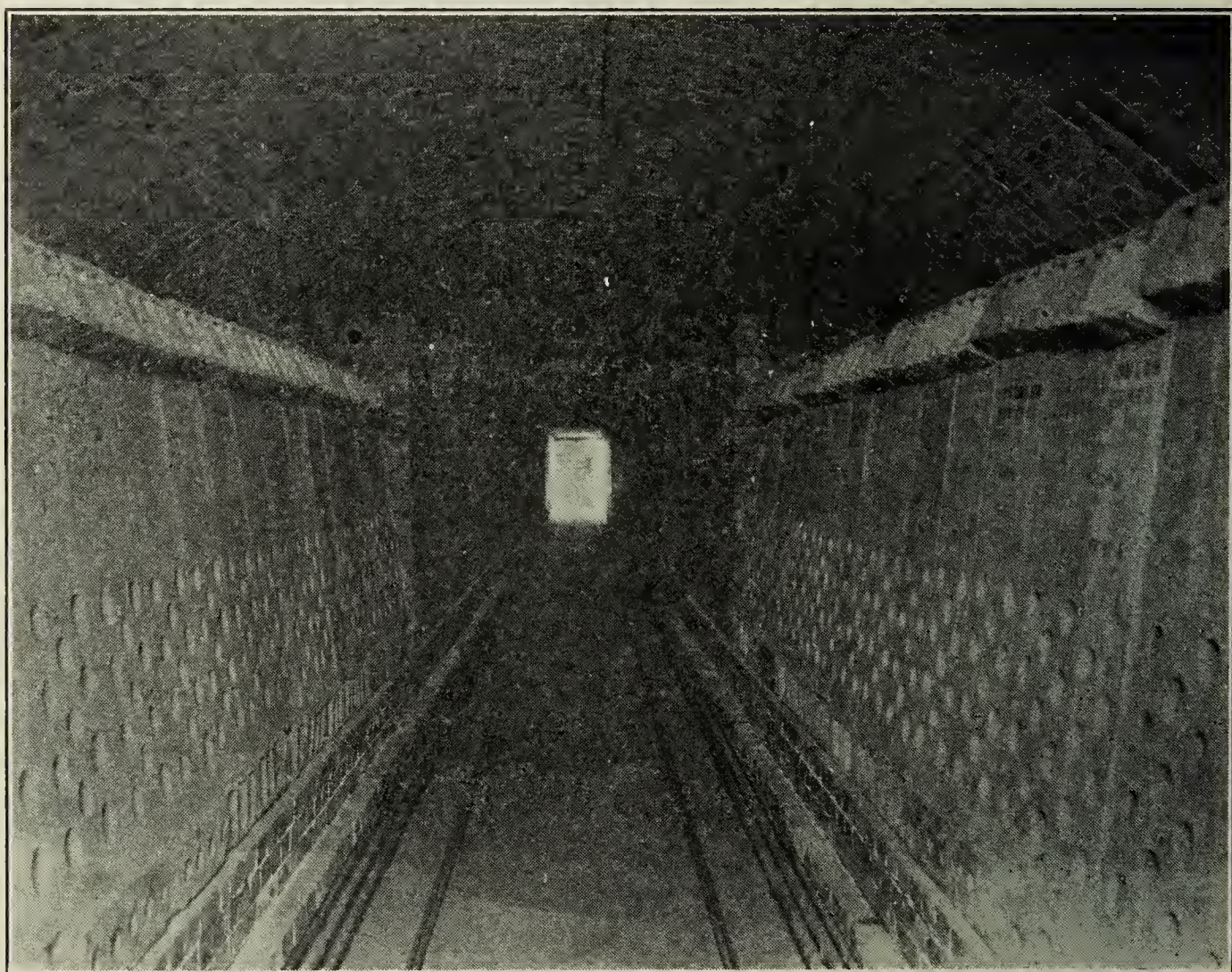
present freight rates are a burden that is sapping the vitality out of a good many plants, giving business to substitute materials and thus materially affecting the market situation in the industry.

Raw materials fortunately are still plentiful and no industry is better fortified with respect to supplies than the brick and tile industry. No estimate of the number of years of supply of shale and clay which is still available has ever been made as there has in the case of iron ore, coal and oil. The various geological ages have furnished this country with a vast and infinite supply of excellent raw materials for brick and tile manufacture—enough perhaps to last to eternity. But this does not mean that the supply of raw material has not affected the development of the industry.

During the period of the last 25 years better clays and shales have been

unearthed. They have enabled the production of higher grade products and those plants better situated have succeeded in weaning business from competing establishments. The tremendous mortality rate in the brick and tile business might perhaps be at least partly attributed to this situation.

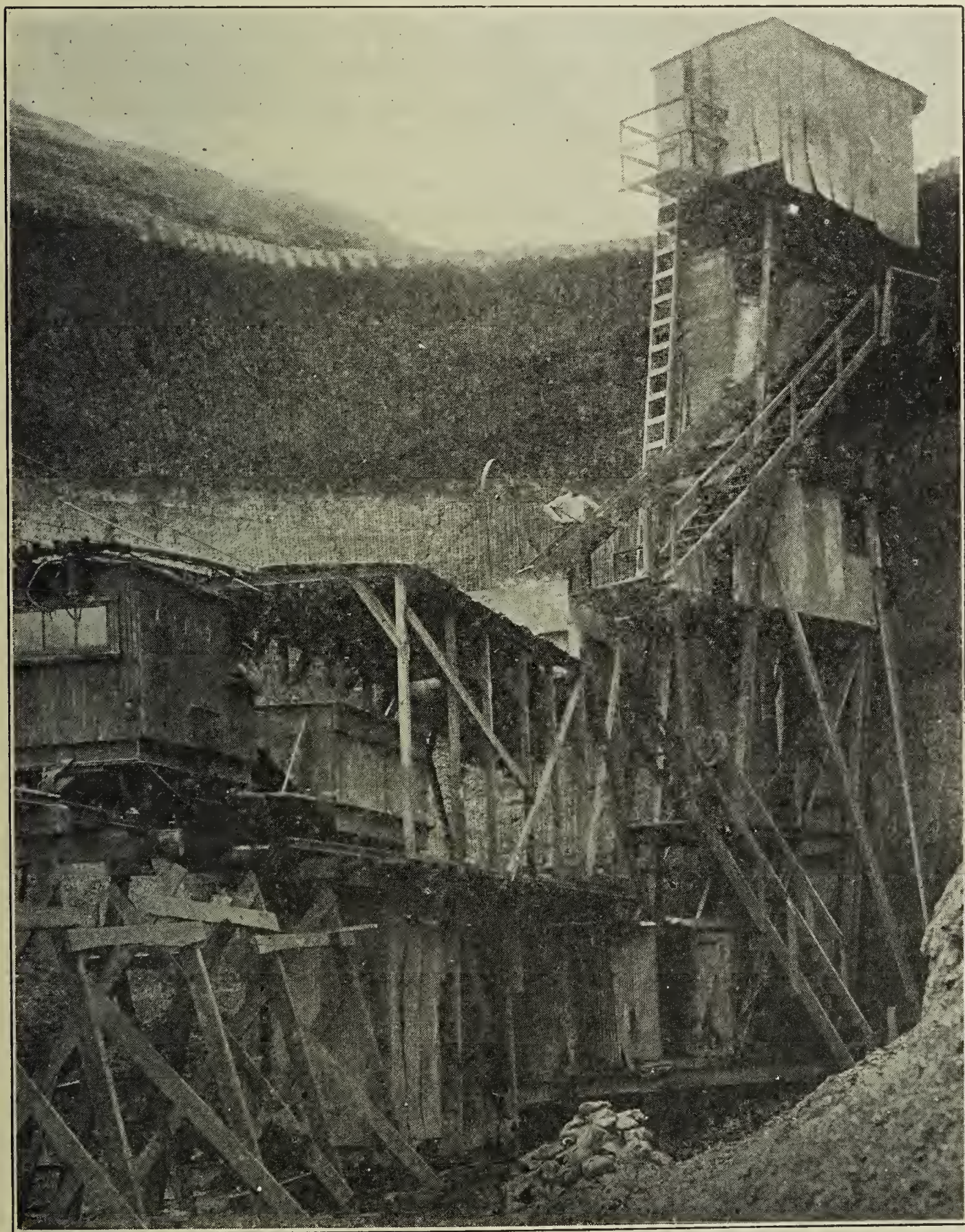
There is, however, at least one section of the country where the supply of available clay has been drawn upon so largely that a lack of raw material is actually threatening the existence of some 15 to 20 plants in that locality. This situation, however, is unusual.



Interior of Dressler tunnel kiln at Bradford (Pa.) Brick and Tile Co.

Labor conditions in the industry have played a vital part in its development. It has perhaps been the greatest factor influencing the development of new machinery and equipment. Cheap labor, which was a keystone of the success of clay plants 25 years ago, has passed. At that time, labor was so plentiful and so cheap that in many instances machinery was actually expensive. The present conditions are altogether different and labor has become very unreliable as well as expensive. The result is that machinery is now cheap and wherever a man is doing the work that a machine can do, there lurks a sore spot which is taxing the vitality of the plant.

It is true that as yet the full significance of the present labor situation is not appreciated by all producers. This is largely because of the great disparity existing in the plane of development of various plants. Shortage of labor has literally forced some plants to become modern industrial in-



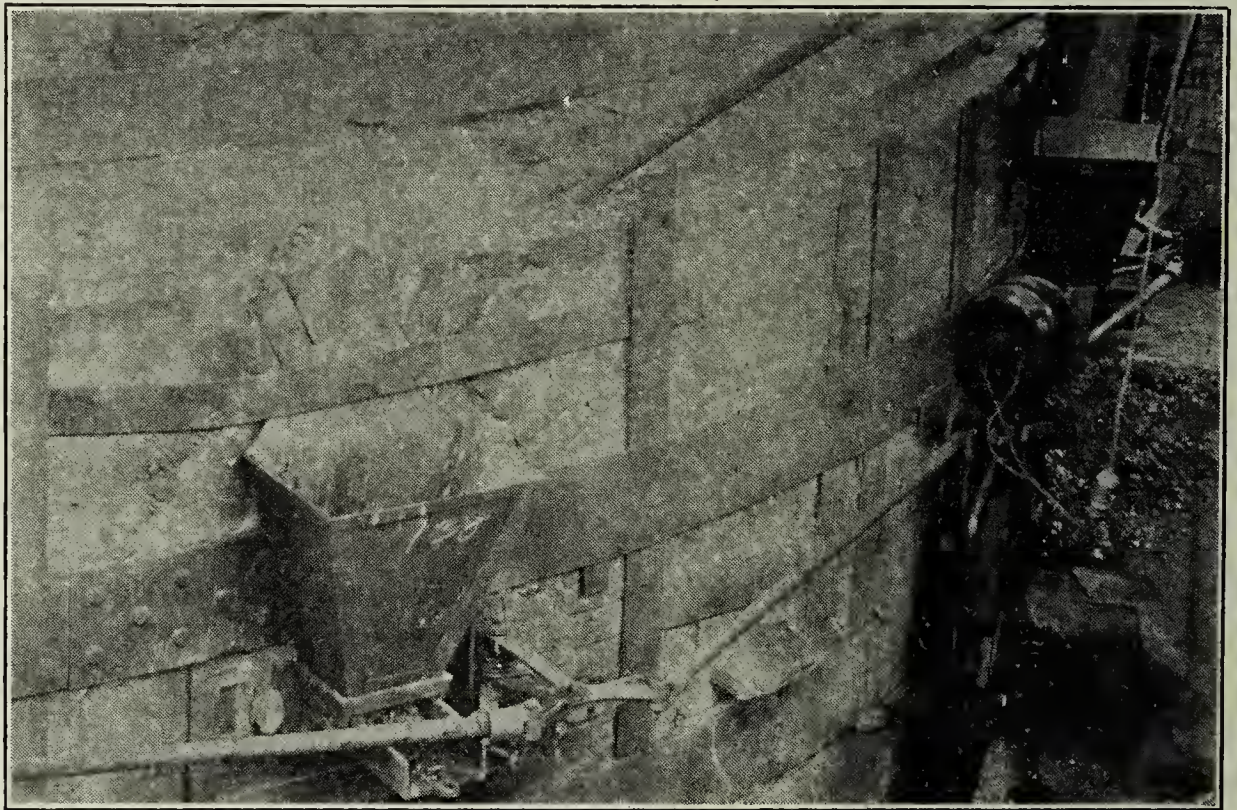
A shale planer in operation and an electric locomotive for clay transportation.

stitutions, while others, generally smaller producers, are still struggling with costly methods, employing men instead of machines. The equipment and methods used in the modern plant are considerably different from those

used 25 years back. This is true in each line of manufacture. In discussing the development that has taken place in machinery used for producing clay ware one must keep in mind that there are three processes in vogue. Brick are made according to the dry press, stiff mud and soft mud processes; tile and sewer pipe are made by the stiff mud process.

As is known to most ceramic men these processes involve different quantities of water in the formation of the working mass. It is obvious that the different consistency of the clay in each case effects a difference in the method of manufacture.

It might be mentioned briefly that dry press machines have been constructed on a larger scale, heavier and with greater compressive power than heretofore. Moreover, they are operated on a different principle which involves pressure from both bottom and top plunger simultaneously and



Mechanical stoker for fireboxes on periodical kilns.

with a movement of the molded brick in the molds under pressure. The early dry press machines exerted pressure only by means of the top plunger. As a result of the new developments a stonger brick and better surface are produced.

Auxiliary equipment recently developed permits the production of a rough texture on a dry press brick which in the past was unheard of and enables dry press manufacturers to produce a rough texture face brick, without a change of any kind in their equipment.

In stiff mud brick and tile manufacture the development has been towards heavier machinery with better parts and higher producing capacity. The combined brick machine and marine thrust bearings are some

items that might be mentioned. It has been only during the recent years that wire cut paving brick has been possible. In this connection mention should be made of the various cutters now on the market including one which places a lug on the wire cut brick.

In the manufacture of stiff mud face brick in the last 25 years important changes have taken place in the nature of the product. In addition to the plain smooth face brick there have sprung up a variety of rough textured brick of all shades and colors which offer the purchaser a great range of possibilities undreamed of 25 years ago.

Up to within five years ago the progress in soft mud brick production lagged. Tremendous changes have recently been adopted, however, and soft mud brick now takes a higher rank than many are ready to recognize.



The "moulder" at work, filling the three-pocket moulds. Many of these brickmakers existed 25 years ago but have since given way to "brick factories."

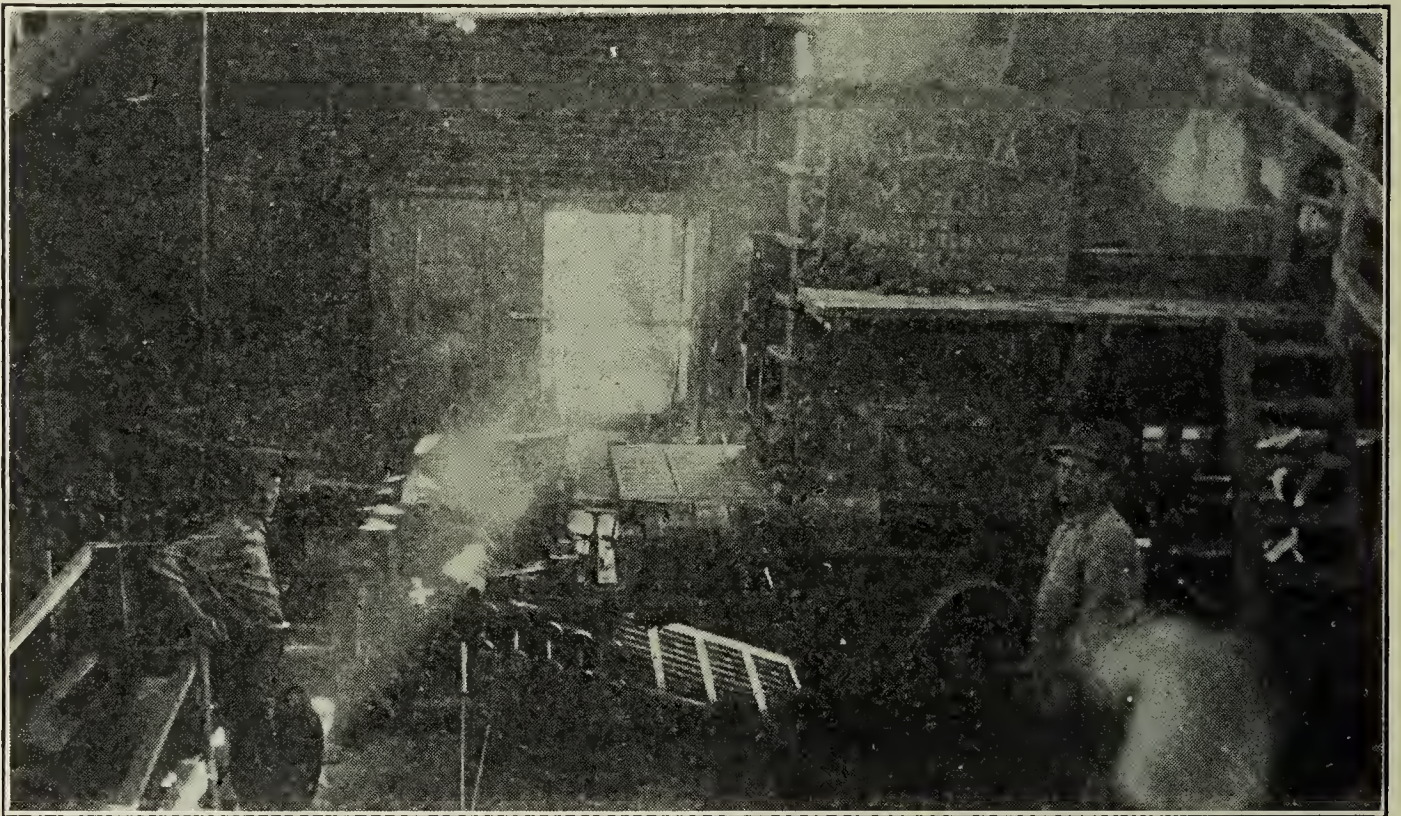
The new automatic soft mud brick machine has cut in half the labor formerly required in operating soft mud brick machines. Sanding, feeding, and dumping of molds are now entirely automatic, making the soft mud brick manufacturer a great deal more independent of his labor.

As with the formation of ware, there has been considerable progress made in every department from the clay pit to the loading platform. Instead of 20 to 30 men with picks and shovels in the pit, you now see but two or three in the up-to-the-minute plant. Horses and two wheel carts have almost passed into memory. In their places, the modern pit equipment consists of some of the following: power drills, steam, gas or electric

shovels; shale planers, traction ditchers; aerial tramways; gasoline, steam or electric locomotives; belt conveyors.

In the clay preparation department the modern heavy duty dry pans were unheard of 25 years ago. Preliminary crushers were practically unknown and vibrating screens had not been considered. Feeders and poidometers were not in use and the modern clay storage was not as now developed.

In power generation and in power transmission there has been noteworthy progress made. Electric motors have been introduced to a considerable extent but the industry has far from completed its installation of more efficient power mechanism. The old steam engine which supplied the entire plant with power is gradually being replaced with the more efficient and satisfactory individual electric power units.



Automatic brick machine for soft mud brick manufacture.

Drying clay ware is a highly important operation. It would be only natural that developments should take place in this department too, and they have been truly great. Contrast what was practically the first method of artificial drying, the hot floor, with the very latest developments, the humidity dryer and you will have a fair picture of the progress in this department. Steam, waste heat and radiated heat dryers are very much at variance in design and operation and the humidity dryer is entirely new.

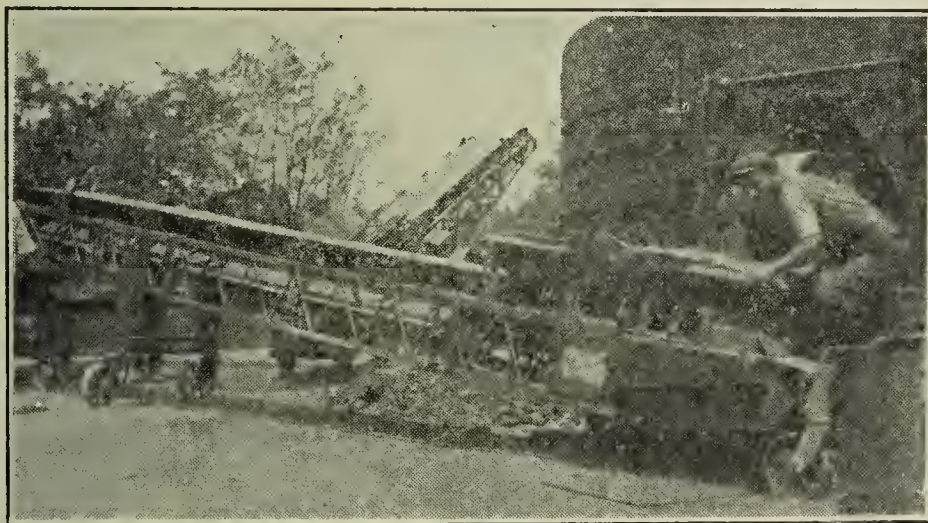
It is in kiln design and operation, however, that the greatest and most tremendous changes have taken place. It is during the last 25 years that the modern tunnel kiln has been perfected and with its use considerable reduction cost of handling of ware has come to pass. All types of con-

tinuous kilns have been improved and the present round down-draft kiln is a great deal more efficient than of 25 years ago. The safest criterion in gaging the measure of progress in burning clay ware is the evolution of innumerable shades and colors of face brick. The consumer now has his choice of anything from white to black and all intermediate shades.

Portable setting and unloading conveyors, gravity conveyors, storage battery trucks are equipment that have been introduced during the last quarter century. Mechanical coal unloaders, and mechanical trucks for coal distribution at the kilns are comparatively new in the industry.

The recent announcement of an automatic stoker for kiln fireboxes is of especial interest in connection with the progress of machinery in the industry. Brick setting and unloading machines for up-draft kilns were revolutionary changes that have taken place in the manufacture of common brick.

As evidence of the transition of the clay industry from a man-operated to a machine-operated one the figures showing the relative horsepower per

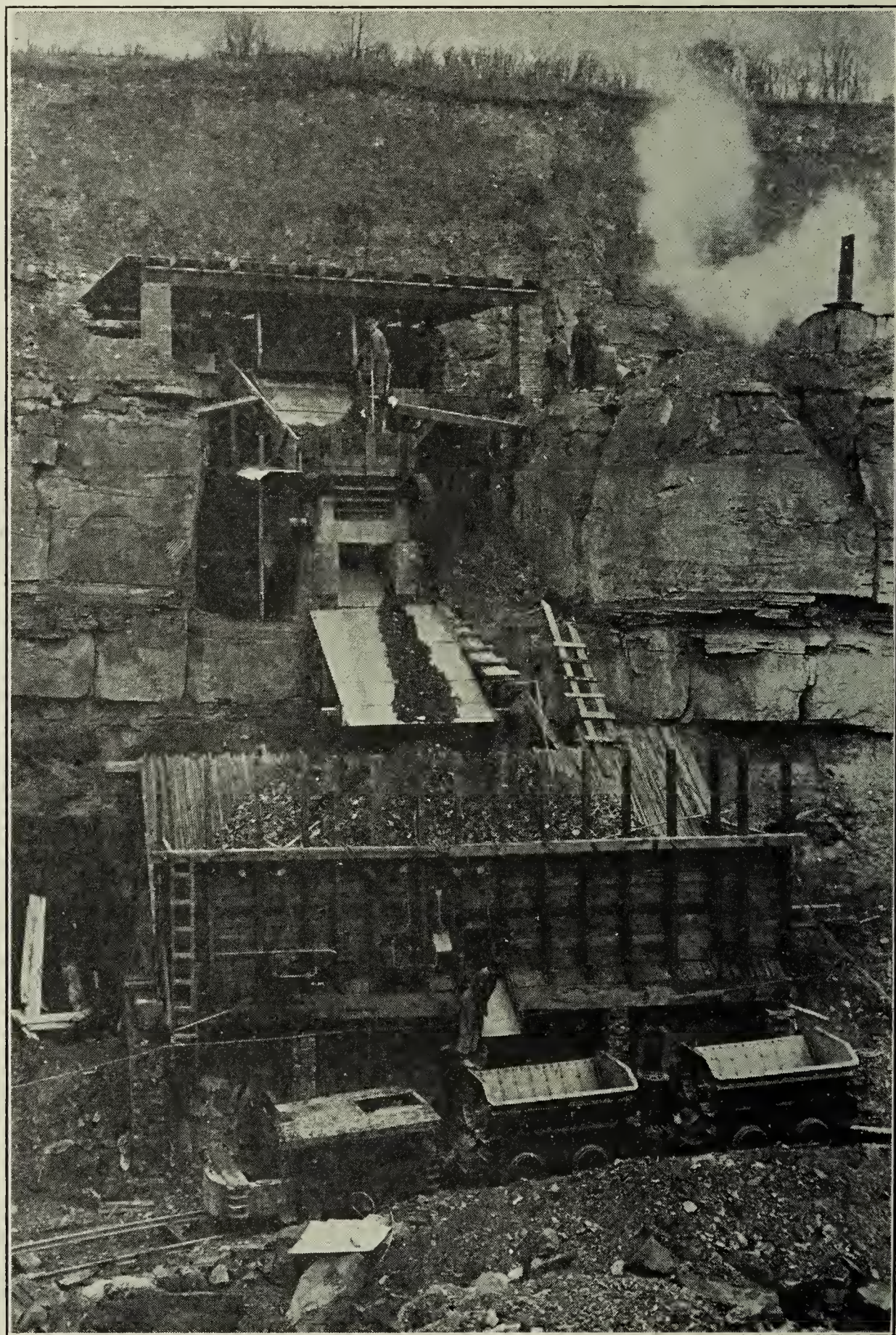


Portable conveyors for unloading brick from kilns to cars or stock sheds.

man in 1914 and 1919 are conclusive proof. In 1914 the horsepower per man was 3.4 and in 1919, 3.7 a gain of 10%. For this advancement manufacturers of clay machinery deserve considerable credit. Their ceaseless efforts to produce better machinery has been no small item in the industry's progress.

The clay products industry is the third largest industrial user of coal. In any industry where coal plays such an important part in the fabrication of the ware, it is but natural that considerable stress would be laid upon the reduction in the use of this commodity in clay ware production. Thus labor and freight rates should not be accredited entirely as being the incentive for the construction of kilns that would save fuel. The continuous burning system, use of fans for expediting burning, the various tunnel and continuous kilns, as well as furnace equipment have had as their main ob-

ject, labor reduction and reduced fuel consumption. Pyrometers and draft gages are also playing an important part in reducing the coal bill of the industry.

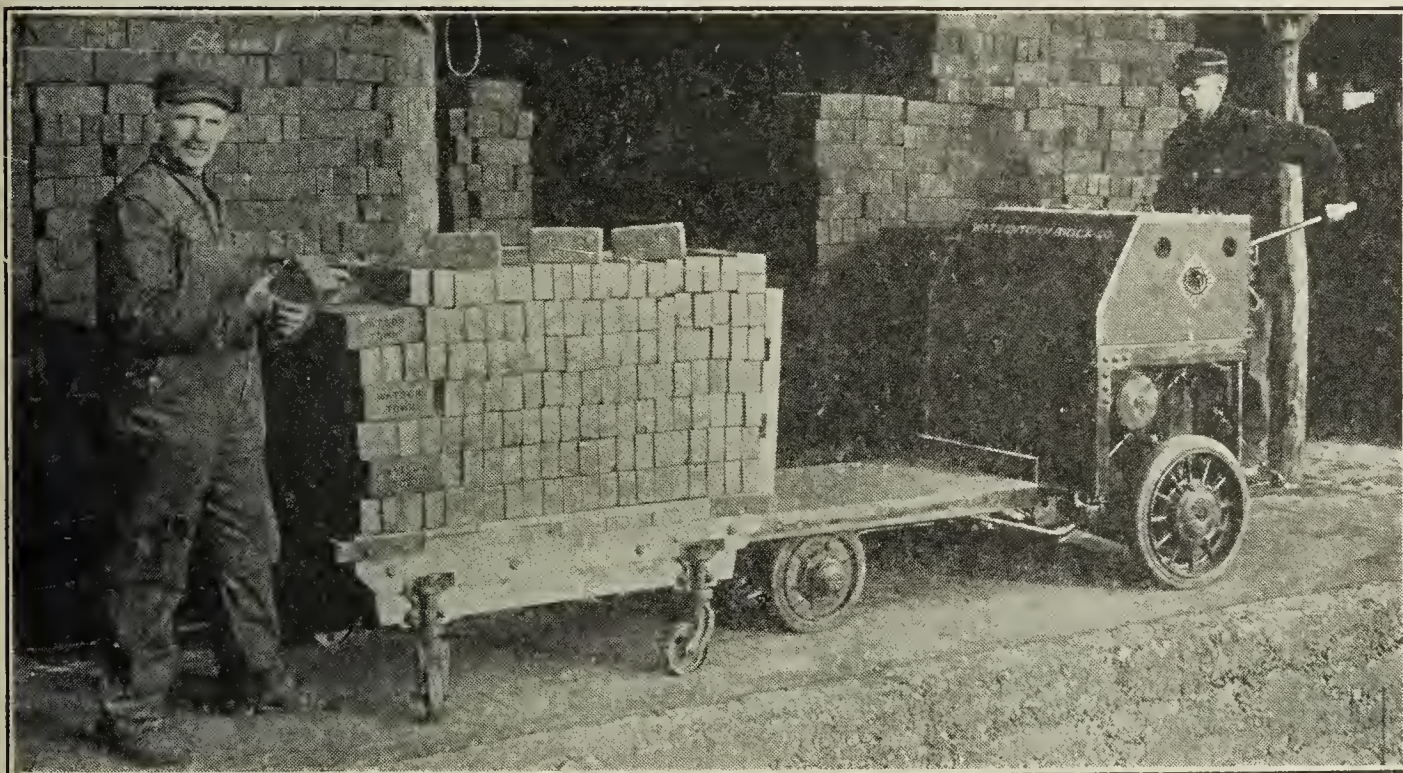


Pit, preliminary crusher, electric locomotive and clay cars at Bradford Brick and Tile Co.

No history of the progress of the clay industry would be complete without mentioning the great forward strides made in the installation and adoption

of efficient cost accounting methods. Manufacturers of brick and tile are realizing more and more that in order to get a fair price for their product they must know what a fair price is, consistent with the cost of production.

In order for an industry to progress its management must have certain ideals and vision. Since management controls the growth and progress of a business, it must follow that management in a clay industry has kept pace with the progress of time. More of the higher grade business men have been attracted into the industry and they, together with engineers who are now found in greater numbers on clay plants, have brought in the ideas and methods of other successful industries—ideas and methods which have assisted toward bringing the industry to its present state of development.



Storage battery lift truck for emptying kilns.

Industrial research was practically nil 25 years ago. The value of an engineer was wholly unappreciated and the many fundamentals of engineering that must be a part of every efficient and successful clay products establishment, were closed to the industry because up to within the last 25 years the doors to that avenue of knowledge had been shut. Nearly all of the national associations and many individual manufacturers have recently conducted or are conducting engineering research. Members of the AMERICAN CERAMIC SOCIETY are quite well informed as to the special investigation conducted jointly by the American Face Brick Association, Common Brick Manufacturers' Association, Hollow Building Tile Association and National Paving Brick Manufacturers' Association in coöperation with various federal government bureaus.

Credit is also due our colleges with ceramic departments who have trained

men to think for the industry and to guide it along the lines of modern industrial development. Many men of broad vision and great ability have been given to the clay industry by the colleges.

The other two factors mentioned at the beginning of the article as having a bearing upon the development of the industry—market and competition—are quite inseparable and might better be discussed together.

During the past quarter century we have seen remarkable increase in the use of cement. The production in 1898 of cement in the United States was something like 17,000,000 barrels as compared with 100,000,000 barrels at the present time. It is only natural that this material should make inroads on the clay products industry's market. The competition due to cement and lumber has caused the gradual falling off of production of brick and tile and made it apparent to manufacturers that something must be done to keep the industry before the eyes of the public. Millions of dollars spent by cement and lumber interests in promotional and propaganda work were focusing the attention of the public upon these products with the result that clay ware was being forgotten and business weaned from it.

The inroads of these substitute materials on the business of the clay industry have served as another incentive for keeping production costs low so that prices might be favorable for competition.

To help combat the influences of other materials important developments have taken place in the products of the clay industries. The most important of these is the adaptation of hollow tile to all forms of construction from the building of a private garage to the erection of America's world-famous skyscrapers. Hollow tile is now used as fireproofing in walls, floors (flat arch construction), steel beams and columns, and many other ways. It has found a use in the building of homes, of sanitary and fireproof farm structures, in fact in practically every construction enterprise.

A development in hollow wall construction has created a greater demand for brick and has made it possible to erect a structure with fewer brick and less labor.

Twenty-five years ago there existed one national association in the clay products industry. This was the National Brick Manufacturers' Association and it was composed of men of various interests. Because of this fact, its effectiveness as a trade association was lost and to make up for this deficiency, the members of kindred interests formed associations in their own fields. It so happens that the AMERICAN CERAMIC SOCIETY was the first organization to have split away from the old National Brick Manufacturers' Association. Following this, the paving brick, sewer pipe, face brick, hollow building tile, and common brick manufacturers formed their respective associations. Each of these associations have permanent,

paid secretaries who are especially trained and efficient for carrying on the activities of their respective associations. Among these activities might be mentioned publicity, preparation of hand books, making of scientific tests, compilation of data, aid in establishing better building codes throughout the country; stimulation in the training of more bricklayers, rendering service in better cost accounting methods, standardization of products and countless other activities.

These associations have spent millions of dollars in publicity and promotional work where formerly not a cent was spent. Individually, the manufacturers are also doing similar work and the association has stimulated its members to better business methods.

Years ago secrecy, cut-throat competition and distrust lurked everywhere throughout the industry. This throttle of progress is well shown by referring to government production records. The formation of associations has dispelled much of this feeling, and through coöperation brick and tile is steadily making progress such as is deserved by a product of such excellent service, quality, beauty and permanence.

Much more could be said concerning the text of this article and matters mentioned above might well have been discussed more fully. However, as previously stated, it is obvious that in the space allotted in a single article only a few of the outstanding features can be chronicled.

CHICAGO, ILLINOIS

FIRE-CLAY REFRACTORIES

By R. M. HOWE¹

The annual production of fire-clay brick has shown a marked growth during the past 25 years because of the increased demands of the metallurgical industries. Established plants have been enlarged, new plants have been built, and in some cases new districts have been developed. Development has probably been most conspicuous in Kentucky, Missouri, Colorado and California.

Meanwhile, there has been a decided change in the attitude towards certain clays. Burley flint clays that were formerly rejected are now being mined and flint clays of all types are being conserved to the fullest extent. Consequently, fire-clay bricks of low or medium refractoriness have replaced those of higher refractoriness in a number of cases. On the other hand, fire-brick for certain purposes contain a larger percentage of flint clay and in some cases are manufactured from this material alone. In general, the tendency has probably been to omit the use of flint clay whenever possible, but to increase it where operating temperatures are higher.

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There is no question but that the mining practice has improved during the past 25 years, for clays that were previously accepted are now rejected, while other clays that were formerly rejected are now accepted. The more general practice of drilling in advance of operations and the use of laboratory tests have contributed to the improved mining practice.

Methods of transportation from the mine to the plant have shown a steady improvement, such conveyances as wagons having been almost entirely replaced by overhead trams, narrow gauge railways, or even standard gauge spurs.

Twenty-five years ago most of the clay grinding and mixing was done in a single operation by the wet process. Today there is a decided tendency towards the dry grinding of each clay, followed by screening, and then by mixing. As a result, it is possible to produce a product of more uniform texture and where automatic measuring devices are used the composition is very regular.

The importance of the water content of the mud is more fully appreciated today and more care is used in its measurement. In a number of cases poidometers are being used in controlling the water supply.

Whereas most of the fire brick produced 25 years ago were made by hand, a very large percentage of the present production is machine made. Soft mud machines, auger machines, dry presses, and in one case a sewer pipe press, have been installed for the shaping of fire brick. Meanwhile there has been a strong tendency towards better workmanship, which is often secured by using a finer grind.

Tunnel and humidity controlled dryers have been added to the equipment of many plants. The rectangular kiln has been replaced in a few cases by round or even continuous kilns. The rectangular kiln is not as economical in fuel as those of the other types, but it is favored where a large number of special shapes are produced. On the other hand, the round kilns are adapted to the burning of standard fire brick and do so at a saving in fuel. Consequently, the kiln equipment of many plants is controlled by the nature of their product. The use of continuous kilns has been retarded in a great many cases by the lack of sufficient space for expansion as plants are often built in decidedly restricted areas. Regardless of the type of kiln there has been a decided tendency towards harder burning.

There has been a marked improvement in the use of refractories during the past 25 years. In some cases the character of the clay refractory has been altered, while in other cases a different type of material has been substituted. The substitution of silica brick for those of fire clay has been the most noticeable and this has resulted in economy to the user as well as in the conservation of flint clay.

Considerable progress has been made during the past decade in the standardization of refractories. Mr. A. V. Bleininger proposed a set of specifi-

cations covering quality (1918), and these were promulgated through the War Industries Board (1918). They were later accepted by the American Society for Testing Materials (1920) and the Refractories Manufacturers' Association (1921).

The work of the standardization committee of the Refractories Manufacturers' Association has been very successful in reducing the number of standard sizes and shapes. This committee found that some 75 so-called 9-inch sizes (including arches, wedges, keys, etc.) were being used in conjunction with standard 9" x 4 $\frac{1}{2}$ " x 2 $\frac{1}{2}$ " straights. After an enormous amount of investigation and study it was found that this number could be reduced to 29, and these 29 shapes are now filling nearly every need formerly filled by the larger number. The resulting economy scarcely needs discussion, for it is evident that the cost of production was greatly reduced, while the problem of carrying a complete line of standard shapes was greatly simplified. As a result, it is now possible to give the consumer better service at a lower cost.

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PITTSBURGH, PA.

CHROME REFRACTORIES

By J. SPOTTS McDOWELL

The first recorded experiments with chrome ore as a refractory were made in open-hearth furnaces in France in 1879; it was used on a large scale in the following year in an open-hearth plant at St. Petersburg. At this plant, crushed chrome ore was used to separate the dolomite bottoms from silica brick. A few years later chrome ore was adopted as a hearth material at several European open-hearth plants, but was supplanted by dead-burned magnesite, which was found to be much more satisfactory.

The use of chrome ore for refractory purposes in the United States began about 1896, when the Harbison-Walker Company began the manufacture of chrome brick. It has gained an important place as a refractory material by virtue of its chemically neutral character and its high refractoriness. It is marketed in the form of brick and of ground unburned chrome ore.

Only a few companies in the United States make chrome brick. These are the Harbison-Walker Refractories Company at Chester, Pennsylvania; Federal Refractories Company, Alexandria, Pennsylvania; American Refractories Company, Baltimore, Maryland; General Refractories Company, Sandy Ridge, Pennsylvania; Lavino Refractories Company, Plymouth Meeting, Pennsylvania.

Chrome brick have always been made very much like magnesia brick.

A bonding material, such as clay or lime, was formerly used but this is no longer done. The brick are now molded in a power press semi-dry, dried in tunnel dryers and burned in rectangular down-draft kilns at an extremely high temperature.

For many years prior to the War, all the chrome used in the refractories industry was imported. The most important deposits are those of New Caledonia, Greece, Turkey, South Africa and India. During the War the demand for the ore was great, and prices became sufficiently high so that California and Oregon ores could be profitably shipped to the eastern industrial centers. Notwithstanding the high cost of transportation imports reached a high figure. Nearly all the ore, however, was needed for metallurgical and chemical purposes and the manufacturers of refractories were able to obtain only a limited amount. At the end of the War the demand fell off, prices dropped, and little or no ore is now being produced in the United States. Imports are coming mainly from South Africa, New Caledonia, India, Greece and Turkey.

In the basic open-hearth furnace the use of a neutral course of chrome brick between the acid and basic portions of the structure is considered good practice. Much ground chrome ore is consumed in patching, daubing, and facing the walls of open-hearth furnaces. On account of its slag resisting qualities chrome has been found to be excellently adapted for the lining of certain parts of such furnaces as soaking pits, heating and heat treating furnaces, forge and welding furnaces, copper settlers and copper refining furnaces.

A review of the literature concerning chrome ore and chrome refractories has been given in the December, 1922, issue of this *Journal*.

HARBISON-WALKER REFRACTORIES COMPANY
PITTSBURGH, PENNSYLVANIA

TECHNICAL DEVELOPMENTS IN DOLOMITE REFRACTORIES

By H. G. SCHURECHT

Sintered dolomite is at present used chiefly for patching magnesite furnace linings since it sets quicker than magnesite when thrown in a hot furnace. Dolomite is not used extensively for new linings since it is not as resistant to slagging action as magnesite and the linings made of dolomite often disintegrate to a powder when the furnace is shut down for long periods. Sintered magnesite is more stable in these respects and, therefore, is preferred for new linings or for patch work when the furnace is shut down. Dolomite, however, is indispensable for patch work while the furnace is in operation.

The comparatively low price and wide distribution of dolomite have stimulated efforts to substitute it for the more costly and less abundant

magnesite. It is very difficult to place dolomite in a "dead-burned" condition owing to its high lime content which causes the calcined product to disintegrate upon storage owing to the unstability of free lime and certain lime compounds which are formed upon calcination. The major portion of the research on dolomite refractories has, therefore, been confined to determining the best methods for rendering dolomite "dead-burned."

The most common method for dead-burning dolomite is by mixing an impurity with the ground material and calcining the mixture at a high temperature.

Numerous patents have been issued and some research has been done¹ on this method of dead-burning dolomite. The following impurities were added: silica, iron oxide, roll scale, flue dust, alumina, chromium oxide, manganese oxide, sodium chloride, kaolin, bauxite, blast furnace slag and basic open hearth slag. The highly aluminous fluxes produced the most stable product since lime combines readily with alumina. Fluxes high in iron produce a product which has considerable free lime owing to the fact that iron oxide does not combine readily with lime and, therefore, the calcine disintegrates upon storage due to slaking. Although highly siliceous, fluxes combine readily with lime they form the unstable calcium orthosilicate, $2 \text{CaO} \cdot \text{SiO}_2$. In cooling the beta calcium orthosilicate changes to the gamma form at 675°C with an increase in volume of 10 per cent. This volume change shatters the material into fine dust in spots often breaking off big pieces of the sintered dolomite.

Such "dusting" may be prevented in the manufacture of dolomite brick by using fluxes low in silica. Silica may, however, combine with the dolomite from the slag and impurities during its use in a furnace. It is difficult to state how vigorous such a reaction would be at present but if very serious the only possible method for utilizing dolomite for refractories would be to separate the lime and use only the magnesia thus prepared.

The separation of magnesia from dolomite may, therefore, become important in the utilization of dolomite for refractories. Numerous methods of separating magnesia from dolomite have been developed. This was done by treatment with MgCl_2 ,² with CO_2 under pressure,³ by calcining dolomite at $500\text{--}600^\circ\text{C}$ and washing out the MgO ,⁴ by dissolving the lime

¹ Davison, G. L., U. S. 792,382, June 20, 1905. Stowe, C. B., U. S. 1,205,056, Nov. 14, 1916. Handy, J. O. and Isham, R. M., U. S. 1,270,818, 1918. Newberry, S. B., U. S. 1,267,686, May 28, 1918. Jones, Fred. A., U. S. 151,535, Jan. 1, 1918. "Experiments in Deadburning Dolomite," *Jour. Amer. Ceram. Soc.*, **2**, 291-305 (1919). "Experiments in Deadburning Dolomite and Magnesite," *ibid.*, **4**, 127-151 (1921).

² Scherer, R., "Der Magnesit A. Hartleben's Verlag," Wien und Leipzig, 84, 1908.

³ "Der Magnesit," *loc. cit.*, 134.

⁴ "Der Magnesit," *loc. cit.*, 134; Mitchell, A. M., "Process for Obtaining Magnesium Oxide from Dolomite," U. S. 1,273,110, July 16, 1918.

with a sugar solution,¹ by treatment with MgCl_2 and NaCl with an excess of NH_4Cl ,² by leaching the calcined dolomite with water,³ by a H_2SO_4 treatment,⁴ by flotation, leaching and screening and elutriation.⁵ It is possible by most of these treatments to obtain a product containing 75–95 per cent magnesia. Whether they can be employed will depend upon the cost of separation and the future price of magnesite.

Although granular dolomite is now successfully prepared, dolomite brick have not yet been manufactured commercially which will stand prolonged storage. This is largely due to the fact that it is difficult to bond them successfully. Heretofore tar has been employed as a binder since it is anhydrous and hence will not slake the free lime. Recently the writer has successfully used sulphate solutions for tempering dolomite brick. By means of these solutions the free lime is converted into the insoluble sulphate thus allowing the brick to be tempered, molded, dried and burned without danger of slaking. After the brick have been fired, they may again be dipped in a sulphate solution and stored indefinitely without danger of slaking. $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ and Na_2SO_4 solutions gave better results than FeSO_4 or $\text{Al}_2(\text{SO})_3$ solutions.

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MAGNESITE REFRACTORIES

By J. SPOTTS McDOWELL

Introduction

The following notes on the technology of magnesite refractories are given in order to add clearness to the historical sketch. The raw material of the industry is the mineral magnesite, MgCO_3 , theoretically containing 47.6% MgO and 52.4% CO_2 . Two types are to be distinguished: the dense and the crystalline. The dense variety is usually snow-white in color and often of high purity; while it usually contains little lime or iron, the presence of several per cent of silica is not uncommon. The crystalline variety is finely to coarsely crystalline and of variable color; it is not often extremely pure, but usually contains slight admixtures of lime, iron and silica. Except for a period during the War, the crystalline magnesite almost exclusively has been used in the manufacture of refractories.

¹ "Der Magnesit," *loc. cit.*, 135.

² Bradburn, J. A., "Process of Obtaining Magnesia," U. S. 1,156,662, Oct. 2, 1915.

³ "Refractory Material and Process for Making Same," U. S. 1,270,819, July 2, 1918.

⁴ Newth, G. S., A "Text Book of Inorganic Chemistry," Longmans, Green & Co., New York, 575, 1905.

⁵ "The Separation of Lime from Dolomite," *Jour. Amer. Ceram. Soc.*, **4**, 558–569 (1921).

The first step in the preparation of magnesite products is selection at the quarry, involving about 50% waste; after that comes calcination of the crude mineral, in order to drive off more or less completely the carbon dioxide with which the magnesia is chemically combined. "This treatment causes a loss of about 50% in weight, a considerable decrease in volume, and marked changes in physical properties. The character of the resultant product is dependent upon the time and temperature of calcination, and the amount and character of impurities present."¹ Magnesite which has been calcined at a comparatively low temperature, 800° to 1000°C, is known as "caustic burned magnesia," and is prized as a structural material on account of its setting and cementing properties when mixed with a solution of magnesium chloride.

"Dead-burned magnesite" results from calcining the mineral at a temperature sufficiently high not merely to drive off nearly all the CO₂, but also to cause sintering of the particles. The product is hard, dense and inert to atmospheric moisture and CO₂. The temperature at which this occurs depends upon the texture and composition of the crude magnesite. One high in iron oxide such as the Austrian, will frit together at 1450°C to 1500°C, while a temperature of 1600° to 1700°C, or higher is required for one low in iron oxide and other impurities. For this reason a small percentage of iron oxide is considered necessary for the production of dead-burned magnesite for refractory purposes. Dead-burned magnesite is marketed in the form of a mixture of nodules or grains varying in size from pieces about ⁵/₈-inch in diameter to very fine particles. It is used for the construction of monolithic hearths in furnaces, and for the manufacture of magnesia brick. The chief value of both the grains and the brick lies in their chemically basic character and their high refractoriness.

Historical Sketch

Twenty-five years ago magnesite had just begun to assume industrial importance as a refractory, on account of its value as a hearth material in the open-hearth process for making steel. This process, which was destined to revolutionize the steel industry, had been introduced abroad in 1879, and had been first adopted commercially in this country by Carnegie Phipps and Company, at Homestead, in 1888.

The first experiments on magnesite furnace bottoms for the open hearth were made abroad in the early eighties. The material utilized was dead-burned grains prepared from the non-crystalline Grecian magnesite. This did not sinter together properly and patches of the bottom sometimes became detached and floated in the molten steel. The addition of fluxing impurities such as clay gave the magnesite a stronger bond,

¹ McDowell and Howe, "Magnesite Refractories," *Jour. Amer. Ceram. Soc.*, **3**, 185 (1920).

but at the expense of its refractoriness. It was finally learned that a crystalline magnesite from the province of Styria, Austria, had the property of readily sintering into hard dense pieces, without fusion. This was attributed to its high content of iron, which amounted to about 7% Fe_2O_3 in the dead-burned grains. Brick made of the dead-burned material were hard and strong and highly refractory; and open-hearth bottoms made of it were highly resistant to the action of slags and the erosion of molten metal. As a consequence the Austrian magnesite had almost completely replaced all others as a refractory material early in the present century, and maintained this supremacy until the beginning of the World War.

The first industrially successful use of magnesite in the bottoms of open-hearth furnaces in the United States was probably that of the Wellman Steel Company, at Chester, Pennsylvania, in 1891.

With the rapid growth of basic open-hearth steel production in the United States during the present century, the consumption of magnesite refractories has greatly increased. The principal application of magnesite is still in the basic open-hearth furnace, but it has become an important refractory for electric heating and welding furnaces in the steel industry and for various furnaces in the metallurgy of copper, lead, and nickel.

A highly important development of recent years has been the complete replacement of siliceous linings by magnesia linings in copper converters. This change has brought about the use of much larger converters, has cheapened converting costs, and has done away with the necessity for continually relining the shell. The siliceous linings were consumed by the iron of the matt, and were usually good for only 20 to 50 tons of matt. In a basic lined converter a record has been attained of over 85,000 tons of matt charged before it became necessary to shut down for repairs.

The first commercially successful results obtained with a basic lined converter were those of Peirce and Smith in 1909. They developed the Peirce-Smith converter, which is a horizontal barrel-shaped vessel. In 1911 the Anaconda Copper Mining Co., developed the vertical Great Falls type converter. These types have proved about equally popular in American smelters.

In 1894 the Fayette Manufacturing Company first manufactured magnesia brick at Layton, Pennsylvania, using calcined Grecian magnesite to which a small amount of iron ore had been added. About 1895 this company began the importation of the Austrian magnesite, which it thereafter used almost exclusively, and in 1902 began the erection of a plant at Chester, Pennsylvania, to be devoted to the manufacture of magnesia brick. At that time nearly all of the Austrian magnesite was supplied by the firm of Carl Spaeter, and was therefore known as Spaeter magnesite.

From 1898 until 1902 Harbison-Walker Company at Pittsburgh made

magnesite refractories from Austrian and from Grecian magnesite by a process like that of the Fayette Manufacturing Company. In 1902 the Harbison-Walker interests obtained control of the Fayette Manufacturing Company and from that time on the Austrian magnesite dominated the field of basic refractories in the United States. At the present time magnesia brick are made at the plants of the Harbison-Walker Refractories Company, Chester, Pennsylvania; American Refractories Company, Baltimore, Maryland; General Refractories Company, Sandy Ridge, Pennsylvania; Federal Refractories Company, Alexandria, Pennsylvania; and Lavino Refractories Company, Plymouth Meeting, Pennsylvania.

The first magnesia brick of American manufacture were made by the hand-made process and dried on the hot-floor. They are now manufactured by the semi-dry process in a Boyd or other power-press, dried in tunnel dryers, and burned at a very high temperature in rectangular down-draft kilns. The brick are made from 100% dead-burned magnesite, with no bonding material.

A special form of magnesia brick used in open-hearth and electric furnaces was devised in 1914 and is known as "metalkase brick." These brick consist of round or square steel containers, open at the ends and of a convenient size for handling and laying, packed with dead-burned magnesite.

Prior to the World War, America had been wholly dependent upon Austria for refractory magnesite. The material was calcined abroad near the deposits and shipped to this country in the form of the dead-burned grains. The grain magnesite was marketed as received for use in furnace bottoms or used in the manufacture of brick.

At the beginning of the War, imports from Austria were suspended and the refractory manufacturers were placed in a most difficult position. Domestic deposits had not been sufficiently developed; American calcining facilities were utterly inadequate; and the magnesite available was low in iron and lacked the bonding properties of the Austrian material. The situation was met by the importation of Grecian and Canadian magnesite; the exploitation of American deposits; and the erection of calcining plants and utilization of existing cement or brick kilns for calcining. At some of these plants the raw material was merely calcined to drive off the CO_2 ; at others the crude or lightly calcined material was mixed with a small percentage of iron ore and dead-burned in rotary or brick kilns at a high temperature.

During the War, sintered dolomitic refractories were developed, and used considerably as substitutes for dead-burned magnesite for furnace bottoms, although not for brick. These dolomitic preparations have been largely replaced by magnesite since the latter again became available in sufficient quantities.

During the early part of the War, the main supply of magnesite came from Greece; in 1917 shipments from this source were likewise suspended. Considerable magnesite was shipped to the United States from the Grenville district, Quebec. This material was not considered desirable on account of the high lime content, and imports from Canada gradually diminished as the American deposits were developed.

For many years it had been known that California contains numerous deposits of the non-crystalline type of magnesite in veins and lenses, usually small. The most important areas are the Porterville district in Tulare Co., and St. Helena, Napa Co. Prior to 1914 about 10,000 tons of crude magnesite were being produced annually of which little, if any, was used for refractory purposes. In 1915 the California output jumped to over 30,000 tons, due to the shortage caused by the War. By 1917 the production had grown to over 200,000 tons, but dropped in 1918 and 1919 to about 84,000 and 60,000 tons, respectively, due to the development of the Washington deposits. Most of the magnesite shipped to the eastern seaboard early in the War was in the crude condition; later as calcining kilns were erected, it was shipped principally in the calcined but not dead-burned form. Calcining was done in bottle-shaped and vertical shaft kilns and in rotary kilns. Upon its arrival in the east this material was dead-burned with the addition of iron.

In 1916 large deposits of crystalline magnesite were discovered in Stevens Co., Washington, and shipments began on a large scale in the following year. The known deposits contain several million tons of high grade magnesite. The most important deposits were acquired by two companies, the American Mineral Production Co., and the Northwest Magnesite Co. In 1918 the latter Company erected a modern plant near Chewelah, Washington, for the production of dead-burned grain magnesite. Six rotary kilns have been installed, with an annual capacity of over 100,000 tons of dead-burned material.

In the latter part of 1920 imports of magnesite from Austria were resumed. This was delivered to the eastern steel centers at a lower price than could be met by the American product, on account of the high transportation costs across the continent. In December, 1920, the Northwest Magnesite Company suspended operations and has been idle since.

In the 1922 tariff bill a duty was imposed on dead-burned grain magnesite and magnesia brick. What effect this will have in stimulating domestic production has not yet developed.

During the last twenty years and particularly during the War period various studies by independent investigators have been made of physical and chemical properties of magnesite refractories. These have been summarized in a paper published in the March, 1920, issue of this *Journal*. Among the most interesting of these investigations are the microscopic

studies of dead-burned magnesite and of magnesia brick. It has been shown that in the burning process the iron oxide combines only slightly, if at all, with the other impurities present, but that it enters into solid solution with the crystals of periclase (MgO), and also combines with MgO to form the mineral magnesioferrite. The latter separates out as minute inclusions within the periclase granules. The value of the proper proportion of iron in magnesite evidently lies in its catalytic action in hastening the formation of periclase crystals from the amorphous MgO , which is the first product of calcination. The lime and silica impurities form silicate minerals, evidently of the olivine group, by combining with the necessary amount of magnesia. Forsterite, $2\text{MgO} \cdot \text{SiO}_2$, has been identified under the microscope by several observers.

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TECHNICAL DEVELOPMENT IN THE FIELD OF SILICA REFRACTORIES DURING THE PAST TWENTY-FIVE YEARS

By E. N. McGEE

Early History of the Silica Refractories¹

Among the earliest known silica bricks are those used in the four striking panels from the celebrated frieze of arches in the Palace of Darius (500 B.C.) now in the Louvre, Paris. These are shown by Bigot to consist of 90% quartzose sand with 10% lime for bond. The same authority has expressed the opinion that they were burned at about 1200°C . They absorb 12% water and are quite refractory though readily glazed. Their refractoriness is incidental, however, as they were used exclusively by the Persians for mural decorations.

Early Development in Europe

The first use of silica brick in Europe was apparently a gradual development due to the demand for a refractory which would withstand higher temperatures without softening under the loads which they had to carry. The character of the clay bricks first manufactured made them unsuitable for withstanding the very high temperatures produced in the furnaces necessary to meet the improved methods of smelting ores and metals. Highly siliceous rocks were then tried, such as pudding stone, granite, Dinas and other quartzites. These were found to be better in some ways but still unsatisfactory. An improvement was then made in the first type of open-hearth furnace by using a lining of siliceous clay which paved the way for the introduction of bricks made from grinding siliceous rocks and bonding with a small percentage of lime or plastic clay. Silica brick were

¹ From "Refractory Materials" by A. B. Searle.

first manufactured in Europe in 1822 by W. W. Young, from Dinas sand, found in the Vale of Neathe in Wales, and sold as Dinas bricks. Their manufacture was also started by the same man in Sheffield in 1858.

Early Development in the United States

Although the manufacture of clay bricks appears to have been introduced in America about 1825, the industry growing and spreading very rapidly, there does not appear to have been any silica brick manufactured until about 1887. These bricks were made at the Star works, now known as Harbison and Walker, and competed successfully with the Dinas or Welsh brick which up to that time had been almost exclusively used in this country. In 1906, the American Refractories Company was incorporated and were the second company to attempt the manufacture of silica brick on a large scale. Thus the beginning of this industry falls within the twenty-five year period and consequently the story of its development covers its progress from the beginning until the present time.

Development in the Field of Silica Refractories

The story of the development of the silica brick industry is very closely related to that of the developments in the metallurgical and by-product coke industries. In fact, the silica brick manufacturer is practically dependent upon these industries for existence. Since the by-product coke industry is to a large extent dependent upon the iron and steel trade, which is by far the most important of the metallurgical industries, it is therefore logical to infer that the output of silica brick is mainly dependent upon business conditions in the iron and steel industry.

Metallurgical Industries

During the past twenty-five years the uses for silica brick have been developed to such an extent that they are now common in the arches, crowns and higher parts of nearly all furnaces and kilns connected with the iron, steel, copper and other metallurgical industries. In blast furnaces they are used because of their ability to sustain a heavy load at high temperatures without shrinkage or warpage. In open-hearth and electric furnaces of all kinds they are used for roofs since they combine the qualities of lightness and refractoriness, and are not materially affected by the chemical action of the vapors. They are used for lining all acid furnaces and usually for linings of crucible furnaces. The roofs and linings of roasting furnaces are also sometimes constructed of this material. They are also generally used in heat-treating furnaces and in the hottest parts of gas-fired furnaces and kilns, including the reverberatory furnace. Formerly checker-work of the open-hearth and reverberatory regenerators, blast furnace stoves

and bustle pipes, was built of clay brick but it was found that silica was much more satisfactory. Silica brick are less readily choked up and do not fuse or vitrify, consequently they give several times the life of a clay brick. Clay brick are usually used in checker-work installations, only for a few bottom courses which are subject to spalling.

The use of silica brick in cupolas is rather uncommon but in some cases it has been found satisfactory. Four or five courses of silica are laid in the melting zone of the cupola, using silica cement to give a tight joint. Ladles are also sometimes lined exclusively, except the top courses, with silica brick. They spall if heated too rapidly on the first pour but after that they can be handled the same as a clay-lined ladle, apparently due to the fact that the brick become slightly glazed.

By-Product Coke Industry.—Silica brick were first introduced in by-product coke oven construction at Johnstown, Pa., in 1899 in some ovens of the Otto-Hoffman type. The Semet-Solvay Company next introduced their use about 1906 and the Koppers Company followed shortly afterward. In this industry as in the metallurgical field, the use of silica brick was a gradual development. Clay brick were unsatisfactory because they softened and shrunk if the operating temperature was carried much above 1200°C. Quartzite brick, or what in England were called Canister brick and in Germany, German Dinas brick, were next tried. These bricks were highly siliceous in character, approximately 80% SiO_2 , and were used for the purpose of eliminating the injurious shrinkage which was so prevalent with clay brick due to the heavy loads which had to be carried. The introduction of silica brick in coke oven construction, however, practically eliminated the use for quartzite brick since these bricks not only solved the shrinkage problem but also stood up at a considerably higher temperature without failure under load and consequently they paved the way for the present coking practices. Instead of requiring from twenty-four to thirty hours to coke a charge of coal in an oven sixteen inches in width, a charge is now coked in an eighteen-inch oven in sixteen or eighteen hours without injurious results to the oven. The expansion characteristics of silica brick are also an added factor in their favor because of the tendency to make tight joints; even the cracks which are opened up when an oven is cooled down for repairs are closed up again after heat is applied, because of this expansion. It is only necessary to leave sufficient expansion joints to take care of any excessive expansion which might otherwise injure the entire structure.

By-product coke ovens are now, almost entirely built of silica brick from the matt to the roof. Clay brick are used in the lower courses of the checker-work of the regenerators, as veneering on the outside and sometimes in the bottom flues to act as a sort of buffer against rapid temperature changes which would be detrimental to the silica brick. Clay brick are

also used in the roof structure where they are not subjected to sufficient heat to cause any injurious shrinkage. When it is considered that approximately the equivalent of 45,000 nine-inch silica brick are required for a single oven, the importance and influence of the modern by-product coke oven industry on the manufacture of silica brick is plainly evident.

Gas Retorts.—The use of silica brick in gas retorts is a common practice and is due to the same factors which have influenced its use in the by-product coke oven.

Glass Furnaces.—The glass industry, which has developed rapidly during recent years also uses a considerable quantity of silica brick in the arches, crowns and higher parts of the furnaces connected with the manufacture of glass.

Lime Kiln Linings.—Silica brick are now being used to some extent for lime kiln linings in the hot zone where they are not subjected to rapid temperature changes. Their use here is possible if the temperature at which the limestone is calcined is not sufficiently high to cause the silica and lime to combine. They have proved successful for this purpose because of their resistance to the erosion caused by the passage down the kiln of the hot and somewhat plastic lime charge.

Beehive Coke Ovens.—Silica brick have also been tried in the beehive coke oven crowns and proved more satisfactory than clay brick. They are used here under conditions which would seem detrimental to their success, because the intermittent use of the beehive oven causes spalling and cracking of oven clay brick. The reason that silica brick can be used in such a construction is no doubt due to the fact that the expansion of the silica and taper of the brick tend to retain the pieces in the dome. It has also been noted, however, that after the brick have been subjected to the operating conditions a short time they become slightly glazed and do not spall as readily as when first put into operation.

Boiler Furnaces.—Silica brick are rarely used in boiler furnaces on account of the inability to withstand rapid temperature changes but they have been tried successfully in a few cases where they were protected from drafts, and where the heating was gradual and the boilers were not forced. In such constructions they outlive clay brick and are free from clinkers. If, however, the boilers were forced, necessitating the use of very high temperatures, the coal ash would no doubt cause injurious fluxing of the silica brick.

Development in the Manufacture of Silica Brick

Although the silica brick industry started in the United States with over fifty years of European experience as a foundation, still the requirements of the three principal industries involved in its growth, the steel, by-product coke, and glass industries, were of such a character that a better

rade of brick was necessary than in European practices. It was only through research investigations, principally carried on by the manufacturers themselves, that bricks of a suitable quality and workmanship were obtained to meet these requirements.

The manufacture of silica brick has not varied greatly since the first few years of its introduction in this country, the progress being mainly toward greater capacity and increased output. It is not the purpose of this article to discuss manufacturing processes only insofar as they indicate development in the methods of manufacture. Surface flow rock was used exclusively in the beginning but solid measure or quarried rock has since been found just as satisfactory. Lime bonded brick were found to meet the requirements best and the limits, as first determined, of 1.5% to 3.0% lime, still prevail. In the hand moulding of silica brick there are two processes, known as semi-dry or stiff mud process and slop mud or what is sometimes called the Anaconda process. For shape moulding the stiff mud process is always used in order that the large or difficult shapes may hold together until dried without squatting. This mud must be pounded and worked into the moulds. Steel moulds are now used exclusively and, in the case of standard sizes, at least six are grouped together so as to make a flat many brick in one operation. For shape moulding, wooden box moulds are used with steel liners which are made in sections. The wooden box is first removed and then each section of the liner is carefully pulled away from the brick. Machine moulding of standard nine-inch brick presents a problem which has received considerable attention during the last few years, but it is not yet entirely out of the experimental stage. The characteristics of silica mud make it much more difficult to handle than clay brick mud in machine moulding. It has been a slow process perfecting the operation so that the moulds will always be completely and uniformly filled, and so that there will not be long and costly shut-downs or repairs. Machine moulding of standard nine-inch brick is, however, proving successful in at least one plant and will no doubt become common practice within a few years as it means greatly increased production with less labor.

After the brick are moulded, the standard shapes are placed on rack cars and run into tunnel dryers heated by waste heat from the kilns while the shape brick are dried slowly on the hot floors. The brick must be thoroughly dried before being placed in the kilns for burning. The kilns are usually round kilns of the down-draft system fired with coal, and will hold (depending upon their size) anywhere from 100,000 to 150,000 nine-inch brick. The setting and burning of the kiln requires great care and it is necessary that the maximum temperature reached be approximately 500°C to insure a proper bond, complete expansion and a hard, tough structure.

Effect of World War and Coal Strike of 1922 on Silica Brick Manufacture

The World War and the coal strike of the past year both had, to some extent, injurious effects upon the manufacture of silica brick. During the War the demand for brick exceeded the production capacity. The attempt to meet this demand, with the shortage in skilled labor a constant drawback, resulted in the production of brick, and especially shape brick, which were below the normal standard, not in quality of materials but in workmanship and structure. The coal shortage during the past year has also had an injurious influence due to the fact that most of the coal which could be obtained was not up to the quality required for the proper burning of silica brick. The effect of these two influences upon most of the consumers has been to make rigid inspection a necessity in order to obtain the quality and workmanship necessary to meet their demands.

Effect of the War upon Research Investigation

The War has also had a very gratifying effect upon the development of the silica brick industry in that it occasioned the necessity for considerable research work to obtain complete information concerning the manufacture and especially the properties of these materials to determine their fitness for various new and improved operations. The enormous increase in the demand for all kinds of products during the War meant production above normal capacity. Where furnaces were used in their manufacture it meant pushing them to the limit with the result that failures occurred much more rapidly than during normal operations. Consequently, came the demand for better refractories and research work was started by a great many manufacturers to determine the proper selection of refractories for various purposes. Thus the testing of refractory materials has become common and methods have been standardized which place their proper selection upon a well-developed technical basis.

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HIGH ALUMINA REFRACTORIES

BY J. L. CRAWFORD¹

High alumina refractories may be divided into two classes: That in which the aluminous material is electrically treated at a temperature higher than those of an industrial kiln during the process of manufacture and that in which the raw material is not electrically treated, such as bauxite, diaspore and aluminous fire-clay refractories. It is the purpose of this paper to deal with only the latter class of refractories.

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There have been some very remarkable developments in high alumina refractories during the past twenty-five years.

Fire clays containing over 40 per cent Al_2O_3 are found chiefly in Pennsylvania, Missouri and Kentucky. In Clearfield and Center counties in Pennsylvania there is found a rough flint clay containing a large number of nodules high in alumina which analyzes 40 to 55 per cent Al_2O_3 and by proper selection a clay containing as high as 60 per cent Al_2O_3 can be obtained. In central Missouri there are a large number of "pockets" of burley flint clay analyzing from 40 to 60 per cent Al_2O_3 . Both of these deposits have been worked to a considerable extent during the past twenty-five years. High alumina clays have been reported in Kentucky, but are of small quantity and have never been separated from the run of mine. Refractories have been made from these clays which have given very good service in resisting high temperature and particularly in resisting slag action in furnaces used in the metallurgical and ceramic industries. Probably the most progress has been made in developing refractory liners for cement and lime kilns.

The tonnage of bauxite refractories produced annually has never been large as compared with other refractories. The difficulty in removing the fire shrinkage in bauxite refractories has been one of the chief drawbacks of this refractory. Bauxite refractories were being used to a considerable extent in furnaces operating at high temperatures and in contact with basic slags until recently, when they were almost entirely replaced by diaspore refractories.

Diaspore refractories are equally as refractory and resistant to basic slag and they have a very low fire shrinkage.

The supply of diaspore is rather limited as the only known deposits of workable size in this country are those in central Missouri district where it is found in "pockets" with the flint clay.

In 1908 a St. Louis refractory manufacturer made a brick containing a considerable quantity of the diaspore found in the flint clay pits. This brick gave very good service and in 1914 they made a diaspore refractory analyzing 78 to 80 per cent Al_2O_3 . This refractory had a fusion point of cone 37 to 40, making it well suited for high temperature work. The demand for this refractory rapidly increased and in 1920 it had almost entirely replaced bauxite. The development of diaspore refractories has been one of the outstanding features of the refractories industry during the past twenty-five years.

DEVELOPMENTS IN THE MANUFACTURE OF REFRACTORIES OF FUSED ALUMINA

BY M. F. BEECHER

The manufacture of refractory articles of fused alumina was begun in this country in 1906. Prior to that time there had been some experimental and development work done in Europe, but first-quality articles had not been produced on anything approaching a commercial scale. This early work on both continents had for its object not only to make refractories, strictly speaking, but also to produce better and cheaper apparatus for the analytical laboratory. Probably because greater difficulties were encountered in making and marketing the former, it was the ceramic bonded, fused alumina laboratory ware (known by the trademark "Alundum") that first became a commercial product in this country.

Up to and including the year 1908 the stock articles manufactured consisted of laboratory crucibles, filter dishes, filter plates and combustion boats. Following this was the introduction of pyrometer tubes and cores, tubes and muffles for wire-wound resistance type electric furnaces. Here is the introduction of the first refractories; *i. e.*, pyrometer tubes and such tubes and cores as are used for high-temperature furnaces wound with platinum or molybdenum.

During the next decade no very extensive commercial developments are recorded. The variety in shape and application of fused alumina articles multiplied rapidly, but it was confined quite largely to laboratory shapes and to small specialties for use in electric appliances. Fused alumina cements ("Alundum" cements) were developed early during this period.

A review of the patent literature during these years indicates a very active interest on the part of inventors. Mention of a few of the patents will serve to indicate that the general trend of these developments was towards adapting bonded fused alumina to new uses and towards the development of new and improved bonds. In the first class may be cited the patents to Jeppson on a refractory cement and on a glazed crucible; to Malm on a pyrometer tube and on a glazed refractory article; to Boeck on a filtering apparatus, a filtering medium and a wire-wound electric furnace construction; to Coolidge on an electric furnace construction. In the second class are the patents to Allen on an alumina bonded fused alumina article; to Saunders on a bondless article in which the mass of fused alumina grains is electrically sintered; to Hall on a cast fused alumina article; to Dentsizen on a bondless alumina article sintered in a molybdenum-wound furnace; to Chappell on an alunite alumina article either with or without a ceramic bond; to Botho Schwerin on a fused alumina article bonded with finely ground fused alumina.

Thus far all the articles marketed were made from high-purity fused alumina (99.0%+) bonded with carefully selected light buff or white

burning clays. A nearly white color, accuracy of dimension and neatness of finish were demanded by the trade. These things naturally operated against the development of large or heavy shapes for strictly refractory uses by keeping the cost at a prohibitive figure.

In the earlier years, between 1907 and 1910, the Norton Company of Worcester, Mass., and Niagara Falls, N. Y., did extensive work in the attempt to develop heavy refractories such as bricks, furnace shapes, slabs, etc., using a lower grade of fused alumina (92 to 94% Al_2O_3), but the results did not lead to commercial production. This can probably be attributed to two principal causes: first, the high cost of the bricks produced; and second, the lack of a sufficient demand for a refractory of exceptionally high quality. The work of that period demonstrated satisfactorily the advantages of the product in places where high softening point, high thermal conductivity, chemical stability, and good mechanical strength are required and where basic slags are absent.

As a result of the growing demand for refractories of better quality which developed during the years 1914 to 1920, the same company in about 1918 picked up again the threads of their earlier experimental work. With a greater demand for better refractories and improved methods for the manufacture of both the fused alumina and of the bonded article, commercial production now seemed more likely to be realized. In this present period of development some very encouraging results have already been attained. It will be interesting to recount a few of these to illustrate the quality of product that is now produced.

Muffle sections for a Dressler tunnel kiln made of bonded fused alumina have now been in service for five months with apparently entire satisfaction. The kiln has not been shut down, so no close examination has been possible. This kiln operates at cone 12, the temperatures within the combustion chamber being from 1275 to 1325°C.

Saggers in the $10\frac{1}{4} \times 4\frac{3}{4}$ -inch size have been used at cone 12, giving an average life of 40 fires per sagger. Under the same conditions the best clay saggers show a life of 8 fires. Although bonded fused alumina is not especially resistant to thermal shock, this record was made in an 8' coal-fired kiln which is regularly set, fired, cooled and drawn in six days.

Fire bricks of bonded fused alumina show no deformation in the standard load test at 1350°C under a load of 50 pounds per square inch. Very satisfactory results of an experimental nature have been obtained with these bricks in the roof of an electric steel furnace. A life of 22 heats or 88 hours' total service has been reached with a probability of its running over 30 heats before replacement.

The improvements in product and process which have taken place since 1906 have been largely in better control and in adapting the molding process to the character of the mixture and the shape of the piece. The

crystalline character of the fused alumina is now maintained at a definite standard. The use of accurate and reliable pyrometric equipment in the kilns makes it possible to regulate the firing treatment according to a definite curve. Whereas the articles first made were formed mostly by casting and dry pressing, it is now regular practice to form some articles by hand pressing in plaster molds, by jiggering and even by extrusion through an auger or plunger machine.

The progress of the last few years has been very encouraging, and it seems safe to assume that the next few years will see even a greater field of usefulness for fused alumina refractories.

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ZIRCONIA REFRACTORIES

BY MARK SHEPPARD

ABSTRACT

1. Outline of physical properties of zirconium ore.
2. Mention of zirconia laboratory ware and method of manufacture.
3. Manufacture and physical properties of zirconia brick.
4. Zirconia cement and its uses.

The discovery, in 1899, of a large deposit of natural zirconium oxide in the Caldas region of Brazil led to considerable research in the development of uses for zirconium oxide. The most important of these are in production of ferro alloys and special refractories.

The fusion point of zirconia containing 99% of ZrO_2 is 2360°C .¹ The natural Brazilian oxide, which contains from 75 to 85 per cent of ZrO_2 , has a much lower fusion point, about 2000°C , which varies according to the composition. The thermal conductivity and coefficient of expansion are both considerably lower in zirconia than they are in the other refractory materials. The specific gravity of natural zirconium oxide is 4.55 while that of fused zirconia is 5.80. This increase in specific gravity is, of course, accompanied by a corresponding shrinkage.

Laboratory Ware

Crucibles, tubes and muffles have been made of zirconia for use in electric furnaces at temperatures up to 2000°C and some of them seem to have given good service.

These articles are made of refined zirconium oxide which has been calcined at a very high temperature in an electric furnace. The usual method of manufacturing crucibles consists of grinding the calcined zirconia very

¹ Otto Ruff and George Lauschke, "Preparation of Articles of Zirconia," *Z. anorg. Chem.*, 97, 73 (1916).

fine, mixing with an organic bond such as starch, shaping the crucible, drying very carefully, and burning in an electric furnace to a temperature as high as that at which the crucible is to be used.

Laboratory ware for lower temperature work has been made from natural Brazilian oxide, bonded with good plastic clay.

Zirconia Brick

Zirconia brick are made from natural Brazilian oxide by a process very similar to that used in making magnesite or chrome brick. Because of the shrinkage, it is necessary to calcine the material at 1450°C or above before making brick.

The calcined zirconia is very hard to grind and it is common to mix about 75% of calcined zirconia ground to pass 20-mesh with 25% of raw zirconia ground to pass 150-mesh. The material is tempered in the wet pan and the brick are made in the special press which is used for making magnesite brick. The brick are dried with magnesite brick in tunnel dryers, and burned to cone 18 in the same kiln with magnesite brick.

The brick have the following characteristics:

Chemical analysis

ZrO ₂	75.02%	Fusion point 2000°C
Fe ₂ O ₃	3.84%	Sheared in standard load test at 1520°C
TiO ₂	0.85%	Porosity 19.41%
Al ₂ O ₃	3.58%	Specific gravity 4.75%
SiO ₂	16.62%	
	99.93%	

The cold crushing strength is greater than that of magnesite brick.

Zirconia brick show excellent resistance to slag penetration. Alkalies and fluorides attack them readily, however.

In the standard spalling test a zirconia brick showed an average loss of 3% each dip until the ninth dip. After ten immersions the brick broke in half. In view of the density and low thermal conductivity of the brick this resistance to spalling is remarkable.

Zirconia brick have been successfully used around the cinder line of forced draft boilers, where the service is very hard, and also in the firing zone of oil-fired furnaces.

The high cost of zirconia brick has been the main reason for the slow development of a large tonnage business, although given volume the cost can be reduced materially. The cost of the brick is below that of some other specialized refractories now in general use, but above that of magnesite and chrome.

Zirconia Cements

Zirconia cements are made from calcined Brazilian ore with plastic clay for a bond. The addition of 10% of clay does not lower the refractori-

ness seriously and makes a cement which is adhesive and which has good working qualities.

A pier of silica brick which contained $\frac{3}{8}$ -inch joints of this cement was heated to 1500°C and held at that temperature for 1½ hours under a load of 25 pounds per square inch. The cement did not show any signs of failure at this temperature. The cement has been used very successfully in laying up malleable furnace bungs and as a protective coating for boiler settings.

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TESTING OF REFRACTORIES

By R. M. Howe¹

Twenty-five years ago most high temperature operations were conducted on a much smaller scale. The temperatures involved were lower and the other conditions of service were less severe. Consequently, less difficulty was experienced in securing suitable refractories and the art of testing had been developed to a very slight extent. Aside from a few chemical analyses and softening point determinations, practically all tests were made under operating conditions. With the use of higher temperatures the problem of selecting refractories has become difficult and the art of testing has been developed to a high degree. The development of several of the more important tests will be considered separately.

One of the oldest tests is that in which the softening or fusion point of the refractory is determined. Consequently, it has been developed to a high degree of perfection and has been standardized by the American Society for Testing Materials. Much of the successful use of this particular test may be attributed to the use of Orton cones. They furnish a cheap, accurate, reliable, and simple method for measuring the point of softening. The publications of Kanolt² are conspicuous in this particular field of testing.

A large portion of the credit for developing a satisfactory method of analysis should be given W. F. Hillebrand and H. S. Washington. Their methods for silicate and carbonate rocks are accurate and reliable although a trifle slow. Modifications of these methods are often made, however, at the expense of accuracy.

One of the most important tests to be developed since 1900 is that in which refractory bricks are tested at high temperatures under pressure. The first experiments were conducted by Lemon Parker³ and reported

¹ Industrial Fellow, Mellon Institute of Industrial Research, University of Pittsburgh, Pittsburgh, Pa.

² J. W. Kanolt, "Melting Points of Refractory Materials," *Trans. Amer. Ceram. Soc.*, **15**, 167 (1913).

³ Lemon Parker, "Action of Refractories under Load Conditions at High Temperatures," *Trans. Amer. Ceram. Soc.*, **7**, 185 (1905).

in 1905. He used fire-clay blocks in the application of pressure to fire-clay shapes in order to develop stronger tile for use in gas benches. His simple experiments led to the development of the load test by Bleininger and Brown¹ (1910), to the construction of special equipment by Montgomery² (1918) and to the more rapid ball impression test devised by Messrs. Unger, Nesbitt and Bell³ in 1916.

Another one of the more conspicuous tests is that in which the refractory brick are heated for a period of time at a relatively high temperature in order to determine their permanency of volume. The first results to be reported were those of Seger and Cramer⁴ in 1900. Loomis⁵ made a number of these tests upon American fire-clay brick in order to develop a relationship between it and the load test. As a result a specification was written and this was later adopted by the American Society for Testing Materials. Ross⁶ made similar tests on silica brick in order to determine their residual expansion. Jones, Harvey and McGee of the Semet Solvay Company contributed to the value of the test by extending it over a period of 72 hours. While this test gives extremely valuable information a number of the results indicate that a further study of the fundamentals controlling the volume changes in fire-clay brick is necessary.

Investigations by Ross,⁶ Harvey and McGee⁷ have shown that the residual expansion in silica brick may be estimated from specific gravity data. Although this practice was first recommended in 1917, its application has already been extensive and has led to results of decided practical value.

Practically all of the contributions to the development of a satisfactory slag test have been made within the past decade. The publications of Brown,⁸ Nesbitt and Bell,⁹ and Fischer¹⁰ are conspicuous. Brown's method

¹ A. V. Bleininger and J. H. Brown, "The Behavior of Fire Brick under Load Conditions at a Temperature of 1300°C", *ibid.*, **12**, 337 (1910); **13**, 210 (1911).

² R. J. Montgomery, "A Furnace for Testing Refractory Materials under Pressure at High Temperatures," *Chem. & Met. Eng.*, **18**, 18 (1918).

³ C. E. Nesbitt and M. L. Bell, "Practical Methods for Testing Refractory Fire Brick," *Proc. Am. Soc. Testing Mat.*, **XVI-II**, 351 (1916).

⁴ Seger and Cramer, "Physical and Chemical Properties of Fire Brick," *Stahl u. Eisen*, **20**, I, 640 (1900).

⁵ G. A. Loomis, "The Porosity and Volume Changes of Clay Fire Brick at Furnace Temperatures," *Jour. Amer. Ceram. Soc.*, **1**, 384 (1918).

⁶ D. W. Ross, "Volume Changes in Silica Brick," *Trans. Amer. Ceram. Soc.*, **19**, 83 (1917).

⁷ Harvey and McGee, "Testing Coke Oven Refractories," *Jour. Amer. Ceram. Soc.*, **4**, 474 (1921).

⁸ J. H. Brown, "A Method of Testing the Corrosive Action of Slags on Fire Brick," *Trans. Amer. Ceram. Soc.*, **18**, 277 (1916).

⁹ Nesbitt and Bell, *op. cit.*

¹⁰ H. D. Fischer, "Looking for a Brick," *Combustion*, Feb., 1920.

involved the heating of brick in a relatively large bath of slag. The method of Nesbitt and Bell is based upon the action of 35 grams of slag for 2 hours; it was adopted as a tentative standard by the American Society for Testing Materials, but has never been accepted as a standard. Fischer determined the fusion points of slag-brick mixtures in order to study the effect of the slag. McDowell and Howe¹ used crucibles made from the refractory material in studying the action of open hearth slags upon basic materials.

Of all these methods, that proposed by Fischer appears to be the most practical and simple; its further development should lead to a satisfactory test.

Most of our knowledge regarding the spalling test has been gained within the past decade, three contributions having been made on this subject. McDowell,² in studying the spalling of silica brick, determined their loss in strength during heating and cooling. Nesbitt and Bell³ have studied the spalling of fire-clay brick by repeated immersions of the hot brick in water. Howe and Ferguson⁴ supplemented this study and found that vitrification, as well as heating and cooling, was a vital factor. This test appears to have been developed to a high degree of perfection.

Other tests that have been developed or applied during the last 25 years are those which determine porosity, modulus of rupture, crushing strength, resistance to impact and abrasion, thermal and electrical conductivity, etc. These have not been applied extensively, however, and will not be discussed in detail.

In closing, the writer wishes to mention the importance of such tests as were inaugurated by J. M. Knote⁵ and continued by Bleininger and Loomis.⁶ The study of raw materials by means of porosity volume change curves gives fundamental information of decided value. The results have a direct application in a great many cases where the requirements are definitely established.

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¹ McDowell and Howe, "Basic Refractories for the Open Hearth."

² J. S. McDowell, "A Study of the Silica Refractories," *Bull. Amer. Inst. Min. Eng.*, **119**, 2001 (1917).

³ R. M. Howe and R. F. Ferguson, "A Study of Spalling," *Jour. Amer. Ceram. Soc.*, **4**, 32 (1921).

⁴ J. M. Knote, "Physical Changes in Clay Due to the Influence of Heat," *Trans. Amer. Ceram. Soc.*, **12**, 226 (1910).

⁵ Bleininger and Loomis, "Properties of American Bond Clays," *ibid.*, **19**, 601 (1917).

IMPROVEMENTS IN THE MANUFACTURE OF ZINC REFRACTORIES DURING THE LAST TWENTY-FIVE YEARS

BY GEORGE C. STONE

Zinc refractories are best divided into two groups: (1) those made by the commercial producers and purchased from them by the smelters; (2) those made by the smelters for their own use.

The first group includes much the larger part of the refractories used and also the greatest variety of shapes and sizes. It comprises linings for smelter furnaces, retort and condenser kilns, melting furnaces and gas producers. A few of the smelters make their own furnace linings, but by far the greater number purchase them in the open market. The improvements that have been made in the manufacture of this class of materials are the same as those that have been made in similar materials for other purposes, and are in no sense peculiar to zinc smelting, and therefore need not be considered here.

The second group of refractories includes retorts and condensers which are made by the smelters themselves. It is necessary that retorts should be made by the smelters as they cannot be burned until they are to be used, and they must be taken from the kiln and placed in the furnaces at once, without being allowed to cool off. Condensers are always made by the smelters but there is no reason that they should not be made by outside manufacturers, although this would seldom be economical, on account of their bulk, which would make the freight on them very high.

There has been a considerable improvement in the manufacture of retorts in all points. Greater care is being given to the selection of the materials; and several companies have devised methods of testing both clay and grog that insure the rejection of unsuitable material. It is becoming more customary to give the materials a preliminary pugging, and to store the mixture in beds or cellars to "rot." Anyone who has gone into one of these cellars will appreciate the appropriateness of this term. In the case of most clays the treatment considerably increases the strength of the material, both dried and burned. The time the mixture should be "rotted" varies with each clay, and must be determined by experiment.

The outstanding improvement in the manufacture of retorts is the general substitution of the hydraulic press for hand work or tile machines. The presses are not only more economical but they give more uniform and durable retorts that are denser and can be made with much thinner walls. This last possibility allows of an increase of 10 to 12% in the capacity of the furnace. This is of itself a sufficient reason for the adoption of the presses.

The first practicable retort press was patented in France, July 24, 1874, by Émile Dor-Delatre, and all of the presses used in this country are constructed on his principle, although many improvements in details and methods of operation have been made here. The Dor press consists of a cylinder, with two concentric plungers that can be moved independently, and two movable heads. The head next the cylinder contains a die that determines the shape of the outside of the retort, and the outer head is solid, merely serving to close the apparatus. To operate, both plungers are lowered, a cylinder of clay is formed that contains sufficient material to make the retort, and is placed in the cylinder of the press. Both heads are locked and the inner plunger is forced up into the clay, driving it up into the die and forming the butt of the retort. The upper head is then unlocked and opened and pressure applied on the outer plunger, which forces the clay out between the head on the inner plunger and the die, forming the retort. This is cut off at the desired length and removed to the drying rooms.

Mr. Dor patented an improved form of his press in this country on May 9, 1905 (U. S. No. 789,451). It presents some advantages but is much more complicated and has not been used here as far as I can ascertain. Improvements in retort presses have been patented by a Mr. Charles Albert Wettengel, of St. Louis, February 25, 1913 (U. S. No. 1, 054,064), and September 29, 1914 (U. S. No. 1,112,103); and by Mr. John J. Simmonds, of Iola, July 14, 1914 (U. S. No. 1,103,320), and February 17, 1920 (U. S. 1,331,285 and 1,331,286). These are extensively used and are reported to give satisfaction. All are improvements in the details and mechanical means of operating the presses and not changes in principle. Mr. J. J. Simmonds built a press with but one plunger, which forced the clay out between two dies, the inner being carried by arms from the sides of the die-head. It was simpler to build and operate than the Dor type, but the necessity of slitting the clay as it passed the arms supporting the inner die and reuniting it was a serious disadvantage.

Many spelter works potteries are now constructed with the drying house divided into small rooms, in which the temperature and humidity can be controlled independently, giving much better and more uniform drying. This also tends to give better and more uniform retorts.

The first machine for forming the cylinder of clay to be put in the press was a drop hammer which forced the clay into a cylinder against the pressure of a ram, which also forced the clay out of the cylinder when the operation was completed. This was slow, did not always give sound cylinders and caused many injuries to the operators. In some plants this has been replaced by a vertical pug mill, which discharges against a ram, or by a horizontal pug mill with a floating shaft. Either of these does more rapid and economical work, without danger to the workmen.

The manufacture of condensers has been cheapened and the quality of the product improved by the introduction of machines for their manufacture. Of these there are two types. In both a ball of clay is placed in a conical mould and a revolving mandrel is driven into it, pressing the clay against the mould and forming the condenser. In the first system, patented by Messrs. J. J. Turner and J. A. Dowler, of Le Harpe, Kansas, February 16, 1904 (U. S. No. 752,484), and also by Messrs. Russell Garrison and George W. Whipple, of Cherryvale, October 19, 1907 (U. S. No. 915,848), the plunger is lowered into the mould. In the second, patented by Lewis E. Vanatta, of Iola, Kansas, October 2, 1906 (U. S. No. 832,177), the mould is raised to the plunger. Both are doing satisfactory work in many places.

Many patents have been taken out for new materials for retorts and for lining retorts but none of them are generally used. The basic retort lining patented by Benjamin Stadtler, February 6 and June 26, 1900 (U. S. 642,722 and 652,332), was used a good deal in the Southwest, when the ferruginous Colorado ores were first smelted, and was reported to give good results. Experience with these ores, however, showed that the same results could be more cheaply obtained by varying the conditions in the furnace and this type of retort has been generally abandoned.

Mr. A. L. Queneau patented the manufacture and use of retorts with linings of graphite, and of retorts containing a layer of graphite between two of clay. Both were tried and showed advantages, but these were not sufficient to justify the increased cost.

Several companies are at present experimenting with new refractories but so far none have progressed far enough to make the results public. It is however probable that some better material than clay will be found.

NEW YORK CITY

THE HISTORY OF THE DEVELOPMENT OF SILICON CARBIDE REFRACTORIES

BY CHARLES F. GEIGER

The possibilities of the use of silicon carbide (carborundum) as a refractory were realized by Acheson at the time he first produced this important compound. In the original patent covering the production of silicon carbide (E. G. Acheson, U. S. Patent No. 402,767, February 28, 1893) its highly refractory character was pointed out. In a lecture before the Franklin Institute¹ he stated “. . . . its three prominent characteristics—great hardness, infusibility, and incombustibility—are sufficient to warrant its extensive introduction into special lines.”

¹ E. G. Acheson, “Carborundum—Its History, Manufacture, and Uses,” *Jour. Franklin Inst.*, Sept. (1893).

No specific mention was found in the limited amount of literature examined under dates of 1893 to 1898 on the use of silicon carbide as a refractory, and it is probable that its commercial applications during that period were not numerous.

On Dec. 6, 1898, Acheson was granted patent No. 615,648 on a method of bonding silicon carbide for refractory uses through the media of iron, iron oxide, or salts of iron. Patent No. 628,288 was granted July 4, 1899, to Benjamin Talbot for a "neutral lining for furnaces" composed of silicon carbide and a bonding agent. F. A. J. Fitzgerald was allowed two patents on May 22, 1900, pertaining to methods of bonding silicon carbide for refractory purposes by recrystallization in the electric furnace.

The first large-scale commercial utilization of silicon carbide for refractory purposes began about 1903 with its use in the manufacture of retorts for the zinc industry in Germany and Belgium. This resulted mainly from the work of Engels who took out several German and English patents covering zinc retorts and silicon carbide refractory paints. The painting of ordinary fire brick with silicon carbide was practiced to a considerable degree, but the results were not marked with much success. However, the use of silicon carbide, in amounts of 60 to 65% with 40 to 35% of fire clay, has been the regular practice in the manufacture of zinc retorts by the more important zinc plants of Germany, Belgium, and France. In 1912 and 1913 large numbers of silicon carbide shapes were made in Germany for special furnaces used in the smelting and recovery of zinc.

An application for United States Patent filed April 25, 1905, by F. J. Tone contained specifications pertaining to the use of silicon carbide bonded with clay and sodium silicate as a lining for brass-melting furnaces. The silicon carbide used for this purpose, as stated in the specification, was the fire sand variety, the amorphous variety, or the crystalline variety. Although this patent was not granted until October 29, 1912 (No. 1,042,844), the original work served as the foundation for a tremendous usage of carborundum fire sand, which is believed to be either mixtures of small particles of crystalline or amorphous silicon carbide or both and silica, or a solid solution of silicon carbide in silica to give compounds of the formula $\text{Si}_x\text{C}_y\text{O}$, for the linings of non-ferrous melting furnaces. The success of the fire sand for certain furnace linings led to its manufacture into shapes for other refractory purposes. These products proved their worth in a great many instances, but as time went on it was learned that it was impossible to make the highest grade of silicon carbide refractories from carborundum fire sand and that it was generally necessary to employ crystalline silicon carbide in shapes for installations other than non-ferrous melting furnaces.

In 1912, F. J. Tone received Patent No. 1,013,700 on the silicidizing of

carbon forms by exposure to silicon vapors to form a special variety of silicon carbide refractory, and previous to that date he was granted patent No. 992,698 on a silicon carbide refractory bonded by recrystallization.

F. A. J. Fitzgerald¹ speaks of fire sand linings, and silicon carbide pyrometer tubes and other shapes formed in the silicidizing and recrystallizing processes; he also makes special mention of the high heat conductivity of silicon carbide. Under the title of "Carborundum Refractories," F. J. Tone² discusses the properties of silicon carbide refractories, describing chiefly the bonded varieties made from crystalline grain. This is the earliest article found in print descriptive of silicon carbide refractories that approach those of present development. A quotation from this article emphasizes a very important point: "when bonded with a clay binder carborundum brick have very great refractory value. However, it is recognized now that the ideal condition to be obtained is that the amount of binding material used be the least consistent with the requisite mechanical strength and that the vitrification temperature of the binder be as high as commercially practical. Failure to realize these essential conditions has been the cause for the indifferent success of Carborundum refractories where their use first appeared most promising."

The foundation for this type of refractory is found in Patent No. 1,204,211 granted to F. J. Tone on November 7, 1916, which, however, was applied for in 1913. This serves as the basis of the present technical development of crystalline silicon carbide refractories in this country.

In 1913, then, the following varieties of silicon carbide refractories were employed in the industries of the United States:

Bonded fire sand, which were made from carborundum fire sand, clay and sodium silicate and formed "in place."

Recrystallized, which were made from crystalline grain formed into the shapes desired and recrystallized in the electric furnace to effect a bond.

Silicidized, which were made by the siliconizing of carbon forms.

Bonded, which were made from crystalline grain with small amounts of refractory bonds and burned in ceramic kilns.

Prior to 1914 recrystallized silicon carbide refractories in the form of brick were being utilized in stoker settings and as base blocks for graphite crucibles, while a number of muffles were in use in heat-treating furnaces.

In the period from 1912 to the present, United States patents were granted on the bonding of silicon carbide for refractories to August Pfaff, T. B. Allen (2), F. J. Tone (3), G. A. Balz, and M. L. Hartmann, and to S. C. Linbarger on the use of silicon carbide in graphite crucibles.

¹ *Met. and Chem. Eng.*, 10, 129 (1912).

² *Ibid.*, 11 (1912).

Just at the time when silicon carbide was starting to make great stride forward into the refractories field, the European war resulted in such tremendous demand for grain for abrasive purposes that except for fine sand for rammed-in linings, it was not available in this country in large quantities for refractory uses. During the years 1914 to 1918 many orders for refractory shapes had to be refused by the largest producing companies because of the scarcity of grain; despite these handicaps, however, noteworthy progress was being made in improving the quality of the product and in the widening of its scope of application. During this period, increasing quantities of recrystallized and bonded brick were meeting success along the clinker line in traveling grate stokers, and the roofs of certain types of electric furnaces were effectively lined with these bricks while the applications of small muffles and pyrometer tubes increased. In this interval also, the clay bonded shapes, because of their lower production costs and ease of manufacture into more difficult shapes, had been replacing the recrystallized silicon carbide refractories. Cements also received attention, and muffles for the Dressler Tunnel Kiln were first made. Retorts for the carbonizing of coal were also produced.

The year 1919 saw increasing use of silicon carbide brick in boiler settings, the first full brick linings in water-gas generators, more hearths and supports for heat-treating furnaces, more roofs for electric furnaces, and more tunnel kiln muffles. During this year silicon carbide refractories were first used in glass lehr construction. The 1920 developments were most important; and in this year was established the first plant in the United States and possibly in the entire world devoted entirely to the production of silicon carbide refractories. Early in 1920 the first porcelain enameling muffle made of silicon carbide was installed in this country. At about the same time a large number of low temperature carbonizing retorts were built. Silicon carbide shapes were finding considerable use in heat-treating and other oil-fired furnaces because of their ability to resist the flame impingement and high temperature. It was known, of course, that silicon carbide could not stand contact with molten basic slags, and it was learned that silicon carbide brick would not endure in settings of boilers that were being operated at high overratings when the mid-western high-iron coals were being burned, because the iron slag attacked the brick. By 1920 the recrystallized refractories had, in a large measure, been superseded by a bonded type burned at high temperatures in ceramic kilns. During 1921 refractories of this type came into considerable usage in oil-fired marine boilers, oil- and coal-fired stationary boilers, combustion chambers for oil, carbonizing retorts, porcelain enameling muffles, glass lehrs, heat-treating furnaces, and muffle furnaces for metallurgical purposes. The use of silicon carbide zinc retorts had also become a standard practice with certain zinc producers in this country. The great

strength of silicon carbide refractories at elevated temperatures allowed the construction of very thin-walled muffles; the high heat conductivity effected fuel savings and production increases to such a degree that in two years these muffle installations increased to hundreds.

In 1922, several periodic kilns with silicon carbide muffles were erected in the pottery industry. During this year all the established lines increased their demands for silicon carbide refractories. The knowledge that has come to light on the efficacy of radiation as a means of heat transfer led to the construction of several types of thin-walled silicon carbide radiating furnaces which insure practically perfect combustion with oil, gas, or pulverized coal and which are capable of consuming sufficient fuel to produce about three times as many heat units per cubic foot of combustion space as any other type of furnace all because of the high heat conductivity and emissivity of property bonded silicon carbide. Chief among the developments along this line was the construction and operation of the first successful furnace ever built for making sponge iron on a commercial scale. This product is used for the precipitation of copper in solution by replacement. As a result of the large output of sponge iron possible for production in the rotary hearth radiating furnace, the established metallurgical processes for the recovery of copper are being revolutionized. During this year radiation furnaces were applied also to japanning ovens, oil mills, and boiler settings.

In the United States at the present writing, silicon carbide refractories find their chief output in the following forms:

Bonded, which consist of crystalline grain with small amounts of refractory bonds and which are burned to high temperatures in ceramic kilns.

Bonded fire sand, which are made from carborundum fire sand and suitable bonds and are "rammed-in" or are shaped and burned at the place of manufacture or are formed at the place of fabrication, shipped dry, and burned "in place."

Refractory cements and furnace washes, which are made from crystalline grain and a series of bonds providing for different vitrification ranges and softening points.

To summarize: Chief among the applications at the end of 1922 are oil-fired furnaces, high and low temperature carbonizing and other retorts, porcelain enameling muffles, glass leers, fireboxes, crucibles, zinc retorts, boiler settings, heat-treating and annealing furnaces, gas generators, muffle kilns, radiating furnace sand linings for non-ferrous melting furnaces.

In the earlier days of silicon carbide refractories the extreme refractoriness and great strength were thought to be the most important properties, but the high heat conductivity and the excellent radiating ability have

proved these refractories to be so eminently successful in the saving of fuel both at high and low temperatures that the major portion of all the installations made are for indirect heating units such as retorts and muffles. With the work that is being done on the development of silicon carbide refractories it is becoming increasingly obvious that the field for the application of these refractories does not lie chiefly in the replacement of natural fire clay and silica in the linings of existing types of furnaces although many successful applications have been found in this field. Today several new kinds of furnaces are being built that depend chiefly upon the utilization of the conductivity and emissivity of silicon carbide refractories. It is rather in this field of new development that this refractory seems destined to offer the greatest service. During the past years many kinds of furnaces and combustion equipment and many proposed metallurgical and chemical processes have been carried forward to the failure of the then available refractories. Within the last three years a number of these have again been attempted, and with the utilization of silicon carbide refractories failures have been turned to success.

In the early introduction of silicon carbide refractories many installations were made that seemed predestined to failure; this was done with the idea of determining the limitations of the material so that once its possibilities were ascertained more attention might be diverted to the successful applications. This accounted for a number of the early failures, as did the fact that it was not possible to make perfect silicon carbide refractories with one or two years' experience. It is now known that the working limits allowable in the production of first quality silicon carbide refractories are very small and that unless an article comes within this small field, even though it may be only slightly under quality, it is unlikely to be successful.

LOOKING BACKWARD IN THE TERRA COTTA FIELD

BY A. F. HOTTINGER

Terra cotta as a building material in the United States dates from the late sixties and was then made in a crude way and in limited quantities for use as a decorative material and was mostly made of red burning clays so that it was often painted and passed for other material.

With the introduction of buff burning clays and the use of grog to control shrinkage and assist in drying, the manufacture of terra cotta broadened and it took its place as a structural building material. It is notable that even at this early date it was recognized that to be durable it was necessary to have a hard burned material, and in looking back it is notable that very few cases of failure of terra cotta through weathering or freezing exist. At this time the use of machinery for grinding and preparing clay was very crude, crushers being of the coffee mill type and fine grinding

being done on buhr mills. Mixing was done by dumping the dry material on the floor, adding water and having men tramp the mixture to coherence when it was put through a pug mill.

With the use of buff burning clays the range of color available increased considerably as it was possible to mix the red and buff clays and also to add the cheaper oxides so that grays, browns, pinks and other colored bodies were made. Also at this time the use of barium carbonate to prevent the soluble sulphates from coming out on surfaces exposed to weather was discovered. Shortly after this period the process of flashing the buff burning clays came into use and this added a new range of color which was very popular for some time.

The introduction of barium carbonate into bodies about 1885 also opened up another important epoch in the industry since with its use it was possible to apply engobes to the buff body which very much widened the range of color, making it possible to use clays and oxides which otherwise would be out of the question on account of the expense involved. With the use of engobes it was also possible to apply a vitreous coating so that the material gained greatly in value.

It may be said that at this point is where the ceramic chemist first became of value to the industry as no great amount of technical knowledge was available, little being published or known.

With the advent of the ceramic chemist some of the problems of the business were brought into control—one of the early and important was the control of burning to secure a thorough oxidation of the ware before reaching the finishing temperature, thus doing away with ware coming from kilns with what was called steamed or pink, and mottled with iron spots which did not match in color.

Until this time or about 1890, no glazed or enameled ware was produced, but with the advent of the tall office building, the demand for this class of material took definite form, since a material was desired which would at once be easily cleaned and reflect light so necessary in the courts of these buildings.

It was but a short step from this point that enameled ware became very popular for the exterior of building and its use spread very rapidly. In its early stages enameled ware was made in a two-fire process, but this, being expensive, compelled the manufacturers to proceed with some technical and scientific research and this may be said to be the point at which the trained ceramist proved to be invaluable to the successful manufacture of this class of work.

As now made enameled terra cotta is universally made by the single-fire method and the various manufacturers have solved the problems involved in various ways, there being a wide difference in enamels and methods used. Clays adapted to the manufacture of terra cotta in the different parts of

the United States varying in their range of heat necessary to produce a good hard body have caused this difference in processes, which extend not only to enamels but also to methods of mixing and drying.

With the ceramist in the laboratory and the researches conducted the range of products produced by the various manufacturers increased and it would take more space than I have to even give a partial list, but at present glazes and enamels in all colors are produced and with the introduction of these, the use of polychrome in architecture is possible and is slowly making a field for itself. It is unnecessary to say that there are still unlimited fields in this direction which give opportunity for research and which will open new fields for this class of material. In the burning of terra cotta no great changes have been made since the necessity of burning in muffle kilns has limited any economics or processes applicable to this class of material.

There are, however, a number of experiments in this direction which promise to make this an interesting field and such possibilities lie in the direction of the tunnel and gas-fired kiln to which much attention is being given.

With the wide market for terra cotta at present and the rapid expansion of the various manufacturers, many problems were passed which demanded attention. Some of these are common to all, but the investigation and research necessary have made it impossible for any one manufacturer to undertake them.

The various manufacturers under the guidance of the National Terra Cotta Society have arranged with the National Bureau of Standards to undertake the investigations. A very large amount of work has been done but nothing of a conclusive nature has been reached. This investigation has in view the requirements of a good terra cotta body and the work so far has included studies in the hardness, porosity, strength and resistance to freezing, but the field is so large that a considerable amount of work is still necessary before any conclusion can be drawn.

TECHNICAL DEVELOPMENT IN THE WHITEWARE INDUSTRIES

BY F. K. PENCE

It is impossible to present within the scope of a brief report a history of the several crafts or even the technical development of the industries concerned with the manufacture of the semi-vitreous and vitreous products. To attempt this would require laborious research and would result in a voluminous report.

Historically considered the manufacture of semi-vitreous tableware was produced at East Liverpool by William Bloor in 1860. This was a true porcelain hand decorated and may be taken as a starting point of the white-ware industries in its evolution from the yellowware. This porcelain was

made on a commercial basis as the ware was taken down the river on trading boats and sold in southern markets. Through a loss of men on account of the Civil War and through financial difficulties the factory was closed in 1863, but from this beginning there were developed later the various types of vitreous products for tableware, electrical porcelain, sanitary porcelain and tiling.

The beginnings of the various phases of the potting industry in Ohio have been listed in the following manner by Wilbur Stout of the Ohio State Geological Survey:

Earthenware pottery, William McFarland, Cincinnati, Oct. 17, 1799

Stoneware, Samuel Sullivan, Zanesville, 1808

Yellowware, James Bennett, East Liverpool, 1840

Whiteware, William Bloor, East Liverpool, 1860

Whiteware, Tempest Brockman & Co., Cincinnati, 1867

Earthen cooking and serving ware, G. H. Bodine & Co., Zanesville, 1878

Sanitary ware, J. H. Baum, Wellsville, 1888

Chemical porcelain, Guernsey Earthenware Co., Cambridge, 1916

Chemical porcelain Ohio Pottery Co., Zanesville, 1916

Door knobs, John Goodwin, East Liverpool, 1845

Electrical porcelain, R. Thomas & Co., East Liverpool, 1884

Beginning with the semi-vitreous products known as general ware for table use we find its development centered chiefly about Cincinnati, East Liverpool and Trenton districts.

Having its origin in England the industry followed the practices of the Staffordshire pottery centers with remarkable fidelity and for many years no fundamental changes in its processes were made. In this respect the peculiar relations between the master potter and the organized operative potters must be considered which have always made innovations difficult to accomplish. Of recent years through the advent of improved drying systems and the tunnel kiln the need of more radical changes is being clearly recognized. The manufacturers themselves have taken active steps to bring about coöperative research and the study of factory problems and have inaugurated a system of coöperation with the Bureau of Standards and other agencies which might well serve as an example of industrial progress. A number of the larger plants have established control and research departments. The question of having one or more laboratories to serve groups of the smaller plants is now under consideration. There can be no doubt but that the general ware industry is entering upon a period of industrial development of no mean magnitude.

The ambition to produce vitreous tableware was in the minds of many early manufacturers and records show that Homer Laughlin in East Liverpool had produced porcelain covered both with high fire and softer glazes and also that the Knowles, Taylor and Knowles Co. produced a

bone china of high quality. But it remained for others to create a typical industry, which followed neither the bone china of England nor the soft bisque-hard glaze porcelain of Continental Europe. They developed a typical, non-absorbent body of a stony rather than glassy texture, possessing extraordinary toughness, and a borosilicate glaze for it. In this they followed the practice of the earlier ware industry in using a higher bisque than glost fire.

In the development of this industry the names of James Pass and Ernest Mayer stand out prominently, both charter members of this SOCIETY. Of these, that of Ernest Mayer is especially noteworthy as he was both a potter and a scientific investigator, possessed of deep knowledge and a broad sympathy, which will ever be remembered by his contemporaries. Mayer did much to promote the vitreous tableware industry and we may say, therefore, that it truly was nourished in its infancy by technical thought. Having more complicated problems than the earthenware industry, more attention had to be given to technical details and we find as a consequence that its leaders were closely affiliated with the work of the SOCIETY. At the present time technical departments are in operation in several plants, and coöperative research work is being done with the Bureau of Standards.

From the standpoint of artistic excellence the exquisite vitreous porcelain made by Lenox Inc., of Trenton, represents the highest development and justly ranks with the most famous ceramic art products of the world.

The production of high fire porcelain was not entirely unrepresented during the years of early development inasmuch as the old Union Porcelain Works of Brooklyn has been in existence for a long period. A strong impetus to this particular development, however, was not imparted to it until the outbreak of the European war when the need for chemical porcelain stimulated its manufacture. In this development the figure of John Herold is probably the most outstanding. It was he who began the making of hard fire chemical porcelain both at Golden, Colorado, and at Zanesville, Ohio, now represented by the Coors Porcelain Co., and The Ohio Pottery Co., respectively. From the technical standpoint the work of the Bureau of Standards in this direction, especially that by F. H. Riddle, deserves mention. The present status of the chemical porcelain industry is such that its continued existence and growth are assured.

With the development of the electrical industries of the country the manufacture of insulating porcelain became a prime necessity and developed into an industry of considerable magnitude. Starting with the making of dry pressed porcelain for low voltages there is now being produced a non-absorbent porcelain of high quality. Among the pioneers in this field there may be mentioned the R. Thomas Co., of East Liverpool, Ohio, and the Locke Insulator Co., Victor, N. Y. The subject of insulator porcelain was first studied from the technical standpoint by A. S. Watts,

whose many contributions in this field are well known. The technical activities pertaining to this branch of industry, both from the electrical and ceramic standpoints are very marked and will tend to be more so in the future as very high tension currents become necessary for the distribution of power over large areas.

The extensive growth of the sanitary porcelain industry parallels the development of modern and typically American requirements. Its home is Trenton from whence it has spread to many other states. Considered from the technical standpoint it has been in the quiescent state for a long time, without the introduction of new manufacturing features. But the pioneering work of C. J. Kirk in the application of the casting process and the tunnel kiln is bearing fruit and more rapid advance is taking place at the present time.

In the field of floor and wall tile we have both vitreous and partially vitrified ware. The principal seat of this industry where its first development took place and the first technical work was done by Langenbeck and Stanbery is Zanesville, Ohio. Ever since Langenbeck's time the technical development has kept pace with the exacting requirements inherent in this product. This industry has furnished the SOCIETY with another of the early presidents, F. W. Walker, whose contributions have been not only along technical lines but also with the organization of an industry for coöperative effort from the economic standpoint.

There might be noted also the development of special porcelains, such as the Marquardt body, used in the making of pyrometer tubes, which was introduced in this country by the Bureau of Standards. The first work on this subject was done by G. H. Brown. The same Bureau has contributed also an investigation dealing with the synthesis of mechanically strong porcelains which possess high electric resistance at elevated temperatures of which the authors are A. V. Bleining and F. H. Riddle. It is possible that the principles brought out in this work may have a bearing on the development of insulators for currents of extremely high voltages.

The keynote of the modern point of view in industrial relations is co-operative effort on the part of the manufacturers belonging to a given branch of industry. Such coöperation is to be both economic and technical. One of the prime needs of this group effort must deal with the perfection of the product in order that it may be possible to combat competitive materials. This must be the fundamental motive underlying co-operative effort and in the striving toward a more and more perfect product, the application of scientific principles to the manufacture of the white clay products will become a matter of necessity. If this general principle is realized we shall be able to maintain the rate of development in a manner worthy of the developments of the past.

A HISTORICAL SKETCH OF THE ELECTRICAL PORCELAIN INDUSTRY IN AMERICA

BY C. C. TREISCHEL,

Porcelain Mixtures

Although the manufacture of porcelain is a very old art—the credit of the origin and development being given to China, where the industry flourished during the middle ages, the use of porcelain as an electrical insulation is comparatively recent. The Germans were the first to use porcelain for this purpose and as nearly as can be ascertained the date of this initial application was about 1852. At that time in attempting to lay telephone wires underground it was found that they could not be properly insulated with gutta-percha, the chief insulating material then in use. Mixing clay with the gutta-percha and finally vulcanizing the gutta-percha with sulphur did not produce satisfactory results. This led to overhead construction but the same troubles of unsatisfactory insulation were encountered. The gutta-percha clay mixture was more satisfactory than the vulcanized material due to the fact that the latter attacked and corroded the copper wires and this fact led to the use of baked clay and finally the more or less vitrified porcelain.

In America so far as the writer can learn the first electrical porcelain was made by the dust or dry process and the credit for this accomplishment goes to the Greenwood Pottery Company of Trenton, N. J. This was in 1879. The articles were two-piece insulators, probably knobs, and were given two firings, one biscuit and one glost. Mr. Joseph Crossley of Trenton made the dies used in making these pieces and at the same time laid the foundation of what is now the Crossley Machine Company.

Mr. David Crossley, now president of the Crossley Machine Company, feeling that the electrical porcelain industry presented a very large field and unlimited opportunities, started experimenting with different articles, bodies and glazes in 1890–91. His samples were fired by the different potters in Trenton. Experiments being constantly retarded by waiting for the return of his samples, a delay of two weeks being customary, Mr. Crossley became discouraged with his arrangement and decided to try glazing an unfired piece just to see what might happen to it during firing. Lo and behold! The piece on coming from the kiln could not be distinguished from his twice-fired samples. Realizing that he had discovered a method of making electrical porcelain at a greatly reduced cost and by a much quicker process, he erected a small test kiln in the cellar of his home and continued his experiments with the one-fire process for two or three years, thus perfecting his formulas. On April 25, 1895, he organized and incorporated the Electrical Porcelain and Manufacturing Company of Trenton, the first electrical porcelain factory in the world to devote its entire production to the one-fire process.

The year prior to the organizing of the Electrical Porcelain and Manufacturing Company saw the first use of electrical porcelain for insulation against high voltages and it was the Imperial Porcelain Works of Trenton, N. J., who in 1894 made our first wet process high tension insulators. Mr. Fred M. Locke of Victor, N. Y., who in 1902 formed the Locke Insulator Mfg. Co. (now the Locke Insulator Corporation), also made wet process insulators about this same time.

Compared with our present insulators for high voltages these first attempts would probably be considered rather crude; but these first manufacturers deserve great credit for, although their product will not stand the criticisms of our present engineers, they laid the foundation of our great (operating and contemplated) electrical transmission lines. And when one considers that in the last 30 years operating voltages have increased from a few thousand volts to 220,000 volts their contribution to the advance of the electrical industry should be still more appreciated.

Machinery and Equipment

With but few exceptions the machines and processes used in the manufacture of electrical porcelain can be said to be adaptations from the general pottery practice. Of course certain manufacturers were pioneers in their introduction but ordinarily the fundamentals come from some other branch of the whitewares industry. This does not mean, however, that the electrical porcelain manufacturers were backward in this respect, but rather that their resourcefulness had to be expended in supplying the rapidly increasing and varying demands of the electrical engineer regarding size, shape and dielectric strength. And the pug mill illustrates this point very well for, although it has been the source of great losses ever since wet process insulators were first made, it is still the universal machine for forming wet process blanks.

As stated above some manufacturers were pioneers in the use of certain machines and processes and a résumé of some of the most noteworthy follows.

The manufacture of wall tubes was at one time a tedious and expensive process but the ingenuity of Mr. G. F. Brunt gave us the machine which upsets the head of the tube so that today such tubes are very inexpensive. And to enable us to have tubes of most any length the Colonial Sign and Insulator Company in 1894 developed the suspension method of supporting them during the firing.

Glaze was at first applied by dipping the ware into glaze vats, but the unfired porcelain pieces absorbed the glaze so rapidly that a thin coating could not be obtained except by the most skilled dippers. Even then small holes in the case of dry process porcelain would become filled and time lost

in cleaning the glaze out of them. August Weber of the Weber Electric Company tried spraying the glaze and found the method satisfactory. Today spraying of glaze is the rule in most dry process plants and some very ingenious automatic spraying devices have been developed.

In the manufacture of transmission line insulators the pull-down jigger was for quite a number of years the omega of development. With this machine one side of the insulator is formed by a plaster mold and the other side by a wood or metal template—the mold of course revolving on the jigger. It was about 1910 when someone (the credit for this innovation has not been determined) tried plunging a heated die into the porcelain mass in the mold. The steam formed by the hot metal in contact with the wet mixture acted as a lubricant and the price of line insulators dropped. Recently the use of metal to replace the plaster mold has been tried and the Pittsburgh High Voltage Insulator Company was the first to use the method in this country.

To the General Electric Company goes the credit of introducing to the industry two pieces of equipment and one process, all three of which were radical improvements over existing methods. These are:

(a) The Continuous Tunnel Kiln	1913
(b) The Casting Process	1914
(c) The Continuous Humidity Drier	1917

In the field of spark plug porcelains the practical use of the French Kneading Table was introduced by the Champion Ignition Company. This company also developed a method of applying surface combustion principles to a continuous tunnel kiln, firing glazed porcelains in open saggars to cone 16 (1917). In 1919, the Jeffery-Dewitt Company, now the Champion Porcelain Co., succeeded in successfully operating a Dressler type tunnel kiln continuously at cone 18, the highest commercial operating temperature for car tunnel kilns in America.

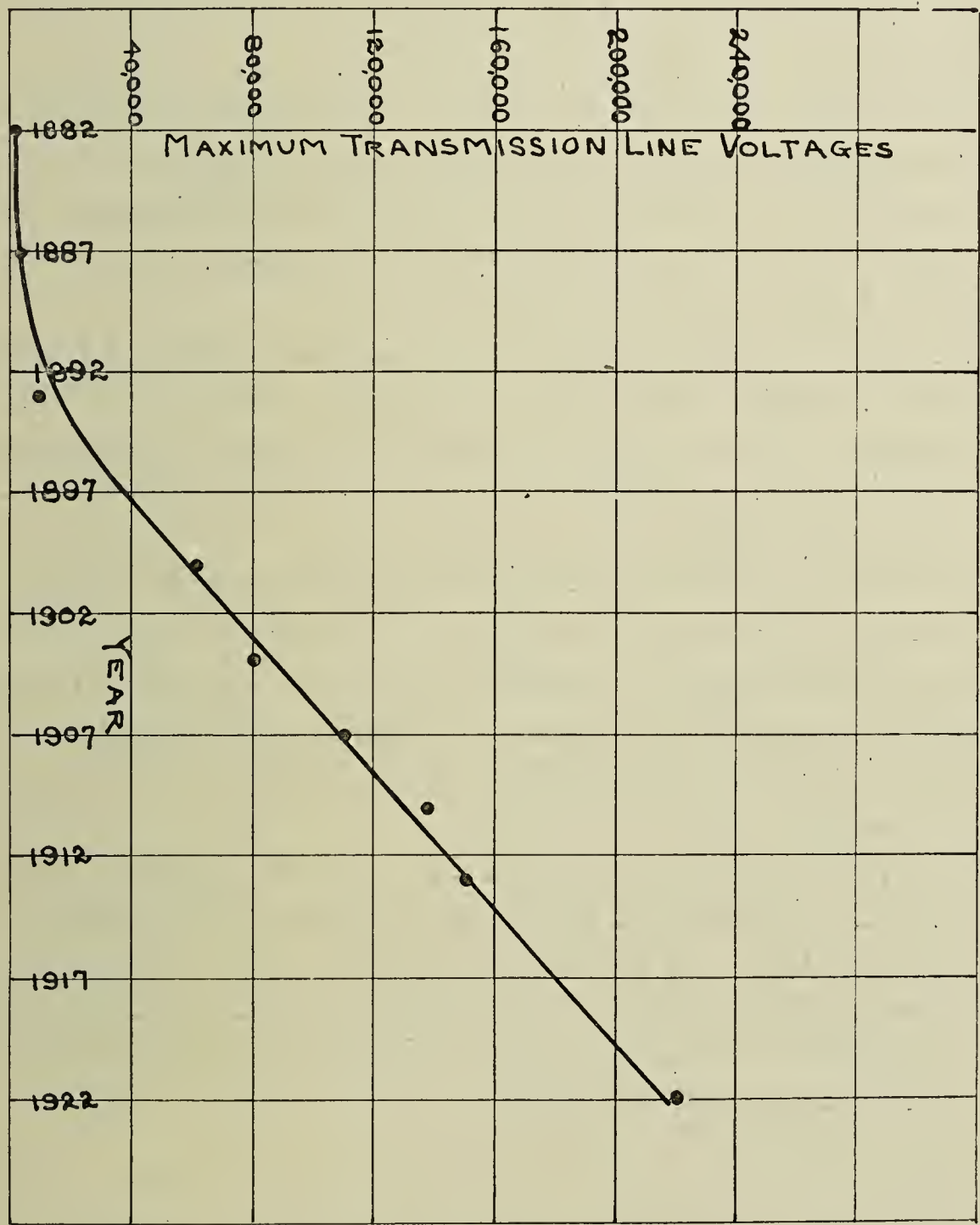
The developments in the field of electrical porcelain have in the past kept pace with the rapidly growing electrical industry. With this growth has come the feeling that technically trained men are a valuable asset, and as there is every reason to believe that the ranks of the ceramic engineers will be kept full, the electrical porcelain industry in America should continue to produce the best electrical porcelain in the world.

GENERAL ELECTRIC COMPANY
PITTSFIELD, MASS.

HIGH VOLTAGE PORCELAIN INSULATORS IN UNITED STATES CHRONOLOGY

BY J. S. LAPP

Up to
1895—Glass insulators used
1895—Use of porcelain ("china") insulators begun. Ordinary whiteware body adopted for high-voltage insulators.



Pioneers—Fred M. Locke, Victor, N. Y.
Frederick Duggan, Imperial Porcelain Works, Trenton, N. J.
J. W. Boch, R. Thomas & Sons Co., East Liverpool, O.
J. Coxen, Electric Porcelain Co., Trenton, N. J.
Aging of clay thought to be valuable.

1898—Fred M. Locke at Victor, N. Y., builds first factory devoted exclu-

sively to high-voltage insulators, introducing brown glaze instead of white, heretofore standard.

1899—First 60,000 volt insulators built by Locke at Victor. 120,000 volt testing outfit installed for these insulators.

Ultimate insulator design reached.

1904—First use of English ball clay for insulators.

Benefits of aging clay thought to be due to bacterial action.

1907—First use of suspension type insulators.

Pug-mill trouble still requires attention.

1910—Introduction of "cast" porcelain for some classes of insulators.

1912—Strong efforts made to introduce German insulators, but without success. One deterring factor was the soft glazes as compared with the hard glaze single fired U. S. product.

Ultimate insulator design reached.

1913—Industry discovers that since adoption of suspension types, extensive insulator failures have occurred. Engineers divided as to opinions of cause. Some say it is due to porous porcelain; others say it is due to relative expansion and contraction of porcelain and metal parts.

Introduction of dye solution impregnation tests for porosity.

Aging of clay considered necessary, especially for difficult designs.

1919—First use of Lapp clay kneading machinery. Requiem for pug-mill.

1922—Growing doubt that ultimate insulator design reached.

Peak voltage for transmission stands at 220,000 with 300,000 volts contemplated.

Ceramic progress during past 15 years as affecting high voltage porcelain insulators marked by greater uniformity in vitrification, better methods of treatment of clay to produce greater homogeneity, and therefore greater electrical and mechanical strength, and the growing conviction that larger improvements are ahead than behind.

THE STORY OF SPARK PLUG PROGRESS

BY TAINÉ G. McDOUGAL

Although as late as 1910 this country was dependent upon Europe for the better grades of spark plug insulation, it is significant of the progress which has since been made that burned insulators and even raw clay bodies are now being exported to both England and France, to be assembled in those countries into plugs for the European markets.

Along with the first developments of internal combustion engines, the

original hot platinum tube ignition, which a strong gust of wind would extinguish, was replaced by the low tension (about 4 volts) "make and break" or "jump spark" system. This latter came into use in France about 1896 as equipment on a one-cylinder tricycle made by de Didion. With the importation of these tricycles most probably came the first spark plugs used in this country; and their general design was practically the same as is used today.

Insulation requirements for this low tension system were not very exacting, even those insulators machined from raw steatite giving acceptable service. •Blin of near Limoges, a manufacturer of small porcelain cups for artists' colors, happened to be using a composition which at that time proved more or less satisfactory for spark plug insulation; and this same concern exported raw porcelain body to this country until the beginning of the War when German occupation interfered.

Just as Blin's body was eagerly "adopted" for the manufacture of spark plugs in France, so at the beginning were American manufacturers satisfied to adopt porcelain bodies as then used in the general and electrical porcelain factories of this country. Soon, however, objections arising from excessive breakage due to temperature shocks demanded that these borrowed bodies be adapted to better suit the special spark plug requirements. At this time better insulating value than that afforded by most any porcelain material was not necessary.

However, during this period of rather slow improvement in quality of product, manufacturers in this country did greatly improve manufacturing processes. Hand throwing and hand turning, which all English and French manufacturers are employing to this day, were early discarded on this side for the semi-automatic throwing and turning machines. While one "hand thrower" could produce only 3000 cylindrical blanks in one day, 17,000 was for some years been standard production for one girl operating the improved throwing machine. During this earlier stage of spark plug development, America forged far ahead in production methods but lagged behind in bettering the quality of the product itself.

Improvement in internal combustion motors soon called for higher cylinder compression and a higher operating temperature. More certain functioning of the spark then demanded higher (15,000) voltage ignition. And for some time improvement in high temperature insulation scarcely kept abreast of the rapid strides of this automotive progress. The same insulation which gave satisfactory service in ordinary automobile motors, actually blocked further motor improvements during the development in 1915, of the Packard 12-cylinder air-plane motor which, with a few changes, later became the Liberty motor of the U. S. Army.

Measurements made with special apparatus, devised in the laboratory of one of this country's largest corporations to compare insulating values

of various materials and compositions at the elevated temperatures prevailing in these high compression motors, disclosed the detrimental effect on thermo-dielectric value of one of the porcelain body ingredients which had heretofore been considered essential in the production of high quality "electrical porcelain." These data which were soon afterwards checked and added to by findings made at the Bureau of Standards laboratories clearly indicated elimination of feldspar to be a most simple and certain procedure to assure an insulator of greatly increased thermo-dielectric value.

The use of any satisfactory substitute for feldspar entailed higher burning temperatures, cone 15 to 16 being necessary with feldspar only partially eliminated, while cone 18 and higher was desirable if it were to be entirely eliminated. With super-refractories not yet available the problem presented was one of refractory kiln materials attending the raising of burning temperatures above the current cone 12 practice. Just as motor progress was awaiting spark plug development so in turn was spark plug progress delayed for want of suitable refractories.

Solution was attempted in two directions—(1) search for better refractories for kiln construction and for saggers, and (2) mitigation of the punishment of those refractories which were already available. Before either of these lines of investigation could be completed the urgency of immediate war requirements for plugs in quantities, later amounting to 40,000 daily, for Liberty aircraft equipment, forced a compromise. Throughout the war all Liberty motors and a large proportion of other aircraft motors used by the Allies were equipped with spark plugs using a feldspathic porcelain insulator fired to cone 15 in periodic coal-fired kilns. The feldspar content was of course reduced to the allowable minimum but no artificial or synthetic substitute was introduced, maturity being effected by use of higher temperatures.

With war pressure relieved, synthetic substitutes for feldspar were commercially developed until such of the better insulations as are now in use can no longer be claimed to have been "borrowed" from one of the older branches of porcelain manufacture.

The idea of lessening the punishment of kiln refractories as mentioned in a former paragraph, led to the development of a tunnel kiln especially adapted to firing spark plug insulators to the high temperatures now in practice. In this kiln the porcelains are passed through in a single layer on the saggers or trays in which they stand, really being a part of the car deck with no super-imposed weight to promote deformation.

The rapid strides made by the spark plug industry have been practically forced by feverish progress in automotive development. This association with the automobile industry first made itself felt in the radical change in production processes effected after but a brief trial of those methods a

first brought from Europe or borrowed from the other clay industries of this country. And as the automotive industry was founded on research, the associated spark plug industry was bound to benefit. Spark plugs were made to meet a demand and so long as the demands of automobile engineers become no more modest or less insistent than they have been in the past, no fear need be held for the future progress of the spark plug industry.

SANITARY WARE MANUFACTURE IN AMERICA

BY R. H. MINTON

Previous to the early '70's all the sanitary ware used in the United States was imported from England. One or two attempts had been made to manufacture it in America but the difficulties were found to be too great, and all efforts had been abandoned.

The first successful manufacturer of sanitary ware in this country was Thomas Maddock, who began its manufacture in 1873 in Trenton, N. J. The difficulties encountered were those which usually attend the beginning and evolution of a new industry. To develop a proper body for heavy sanitary porcelain was quite different from making table or toilet ware. To this was added the lack of skilled operatives, all of whom had to be trained. There were no kilnmen who knew how to place such large pieces. The glaze dippers did not know how to handle such ware. As a result the kiln losses were extraordinarily heavy due to warping, dunting and crazing.

After much time, with great perseverance and unceasing labor, Mr. Maddock finally succeeded in producing an article that compared with the imported product. Even then it could not be sold except when stamped with an English brand.

The development of sanitary ware marks the development of sanitary engineering. Plumbing has made possible modern civilization in cities, and has been the greatest single factor in advancing the health of the human race.

The most important product of the sanitary potter has been the water closet. This was first introduced in about 1850 in London. The beginning was of a crude form and its evolution has been through the usual successive steps to perfection. Many inventions marked the progress of its development, the principal ones relating to the flushing rim and the siphon jet. The present style of improved bowl is a combination of all of the best principles.

It is interesting to note that in America the development of sanitary ware has always been in advance of sanitation generally. In fact, the manufacturer of sanitary ware has been a better promoter of modern sanitation

than either the plumbing trade or the medical profession. As a result sanitary conditions in America are superior to those of any other country in the world.

The improvement in sanitary ware has been largely due to the operation of the potter, who has made it possible to produce in an impervious clay body the most difficult and intricate shapes. While the old fire clay closet bowl is still used to a large extent in England and Europe it is unknown in the United States. The sanitary ware of this country, both as regards quality of ware and perfection of design, is superior to that of any other country.

The sanitary ware industry may be divided into two branches: the vitreous china ware, including principally closet bowls, tanks, and lavatories, and the so-called "solid porcelain" plumbing fixtures, bath tubs, wash trays, kitchen sinks, lavatories, urinals, shower receptors, slop sinks, etc.

The industry is one in which a large amount of hand labor is involved. The great bulk of the ware is formed by hand and so far no serious attempts have been made to form by machinery except in case of tanks. There seems to be no reason, however, why certain types of lavatories cannot be formed by machine pressing.

Perhaps the greatest departure from the old method is in the casting system of forming the ware. The casting method is quite generally used in Germany, and to some extent in England, but has not until recently been given serious consideration in the United States. In the greatest sanitary ware center, Trenton, casting has not made much headway due to opposition on the part of the union operatives. In the newer plants of the middle West casting has been extensively employed. Owing to the present strike among the employees of the potters in the Sanitary Potters' Association it is likely that casting will receive a great impetus in the East.

The other most important development that is now being tested in the industry is in the use of the tunnel kiln. It is too early to reach a definite conclusion as to the results. In some plants it has been reported to be a success, while in others the particular type used has been a complete failure. Some eight or ten kilns have been built, or are in operation, in this industry and their development is being watched with great interest.

In England there has been developed a compartment kiln which is giving great success in the firing of sanitary ware. It seems likely that a kiln of this type will be a great factor in the future development of firing in the industry. Both the introduction of casting, and a more compact and economical method of firing, should make great headway on account of the necessity for eliminating labor and reducing costs.

From the single firm started in 1873 by Thos. Maddock (now known as the Thomas Maddock Sons Co.) the industry was rapidly expanded until there are now more than sixty firms engaged in the manufacture

itary ware. Of these about eight or ten are making the heavy grog
re while the others make vitreous ware. The output of the manufac-
ers of vitreous sanitary ware have a capacity equivalent to about 300
ehive kilns which include the equivalent of that through the tunnel
n. The industry employs approximately 6000 employees and the yearly
oduction value will approximate between \$25,000,000 and \$26,000,000.

GENERAL CERAMICS COMPANY
METUCHEN, N. J.

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The following is a list of books to be found in the libraries of the University of Illinois, New York State School of Ceramics, Carnegie Library of Pittsburgh, Ohio State University and the private library of F. H. Rhead. Thanks are due to the librarians of the ceramic departments and especially to E. H. McClelland, Technological Librarian of the Carnegie Library, of Pittsburgh. There has been no attempt to prepare a *complete* list of ceramic books, this list being compiled only in response to many inquiries for titles of books to be found in the libraries.

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ORIGINAL PAPERS

IMPACT TESTS ON TABLEWARE¹

By H. H. SORTWELL

ABSTRACT

Impact tests were conducted on sets of plates of six thicknesses covering the range of from $\frac{1}{8}$ to $\frac{3}{8}$ inch, contributed by five potteries, three making semi-porcelain and two vitrified china. The plates were struck in the center and both "starring" and complete failure were observed.

It was found that in all types tested the impact to cause “starring” increased with the thickness in an approximately parabolic relation.

In plain semi-porcelain household plates and rolled edge vitrified hotel china difference in thickness within the range in which such ware is ordinarily made, had no appreciable effect on the ability of the ware to withstand complete failure by impact.

In the double-thick semi-porcelain hotel plates tested the strength increased with increase in thickness and the ultimate impact strength was much higher than for the other types, probably due to the reinforcing effect of the heavy rim.

Introduction

Results of impact tests made on seven-inch plates at the Bureau of Standards showed that somewhat wide variations in thickness exist in different brands of ware as marketed. Since the relations between thickness and resistance to impact were not known, it became apparent that additional tests would have to be made to provide data on these relations

¹ Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

before satisfactory comparisons of results on specimens of different thicknesses could be made.

This problem was discussed at a joint meeting of the Research Committee of the United States Potters' Association and the Bureau of Standards, and several members of the committee offered to have plates made covering a wide range in thickness for this purpose.

Testing Procedure

Samples were submitted by five potteries, three making semi-porcelain and two vitreous hotel china. The plates were jigged in six thicknesses to cover the range from 1/8 to 3/8 inch, and were divided into three sets which were fired in the first, second and third rings in the bisque kiln. The plates were then glazed as usual.

The method of testing consisted in striking the plate in the center with the bottom resting against three one-eighth inch steel balls equidistantly spaced around a ring three and one-quarter inches in diameter, which has been previously described in detail.¹ The first blow had an energy of 0.025 ft.-lbs. and each successive blow was increased 0.0125 ft.-lbs. The first occurrence of "starring," any failure of glaze or body, and the final failure when the plate was completely fractured or cracked enough to be pulled apart by the hands, were observed.

Results

The results of the tests are given in Table I. Since the results on plates

TABLE I
RESULTS OF IMPACT TESTS

Ware	Average thickness in inches	Average blow causing "starring," ft.-lbs.	Average blow causing failure, ft.-lbs.
No. 1 Semi-porcelain	0.130	0.0498	0.1907
	.176	.0620	.1815
	.219	.0977	.1814
	.275	.1554	.2004
	.331	.2408	.2608
No. 2 Semi-porcelain	.382	.3588	.3668
	0.140	0.0358	0.1802
	.173	.0495	.1704
	.225	.0826	.1782
	.268	.1300	.1982
	.307	.1812	.2140
	.352	.2746	.2879
	0.178	0.0544	0.2756
	.203	.0659	.3366

¹ H. H. Sortwell, *Jour. Amer. Ceram. Soc.*, 5 [6], 276 (1922).

No. 3	0.241	0.0899	0.3787
Semi-porcelain	.260	.1174	.3771
	.308	.1561	.3931
	.347	.2265	.4423
	0.120	0.0383	0.1979
	.155	.0534	.2387
No. 4	.172	.0708	.2316
Vitreous china	.210	.1103	.1995
	.245	.1708	.2108
	.281	.2092	.2356
	0.113	0.0375	0.1541
	.143	.0550	.1562
No. 5	.169	.0875	.2250
Vitreous china	.210	.1012	.2250
	.247	.1750	.2185
	.274	.2410	.2875

of the same thickness fired in different rings in the bisque kiln varied but little and not always consistently with the variation in heat treatment, space is taken in this publication for only the average for the plates of each brand and thickness. Comparison of the results on plates of the same



FIG. 1.—Results of impact tests on plain semi-porcelain household plates (Ware No. 1).

thickness fired in different rings in the bisque kiln showed that ware uniform in respect to this test can be burned in the ordinary potter's kiln.

Fig. 1 shows graphically the results on plain semi-porcelain household plates of one make. The results are the average for thirty plates of each

thickness. The upper curve indicates the blow at which the plate broke, while the lower curve shows the first occurrence of "starring."

Beginning at a thickness of 0.130 inch, with increasing thickness the ultimate strength first showed a slight drop, followed by a slight rise to about 0.275 inch, after which further increases in thickness increased the strength more abruptly. Between these thicknesses the thickness appeared to have only a slight effect on the ability of the ware to withstand blows as indicated by this test, and in comparing plates of this type differences in thickness within this range might be ignored. Practically all American semi-porcelain household plates fall between $\frac{1}{8}$ and $\frac{3}{16}$ inch in thickness of the bottom and the curve shows that little is to be

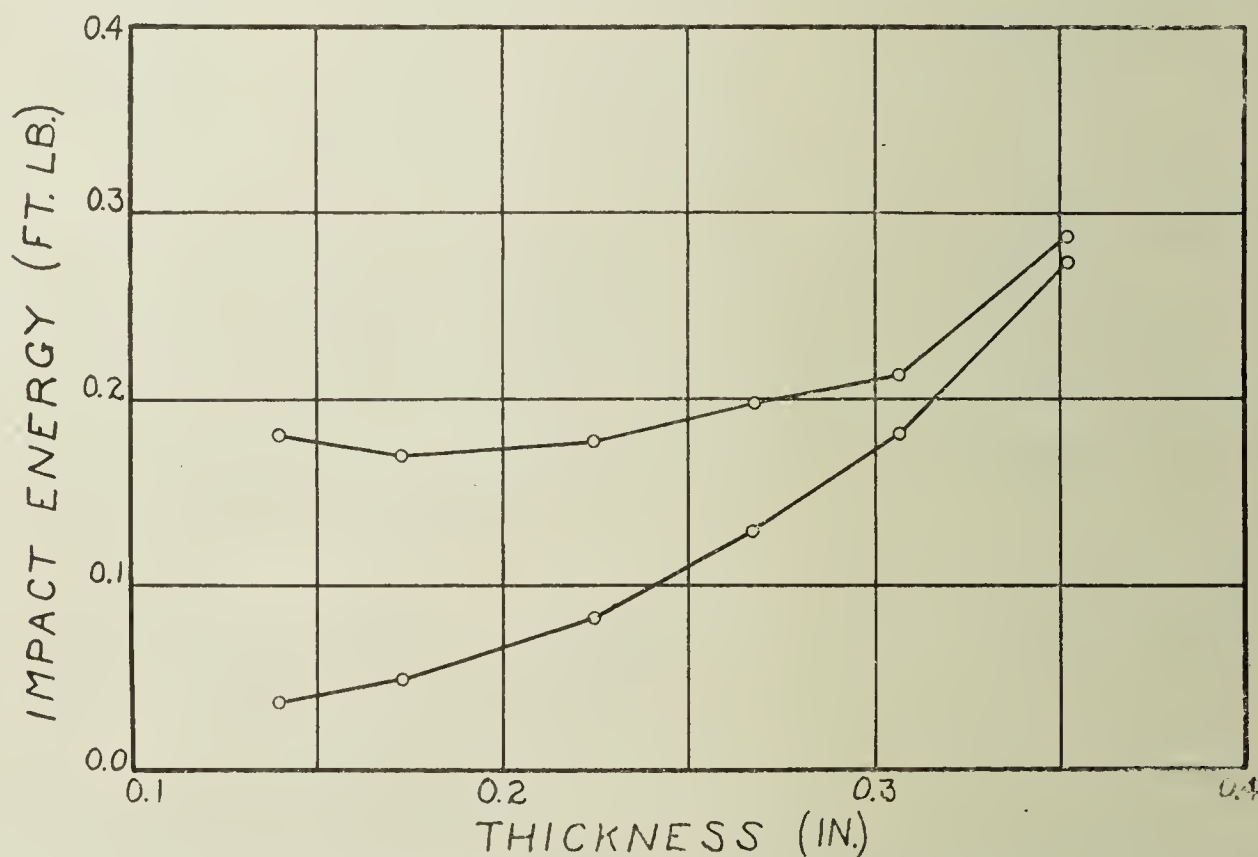


FIG. 2.—Results of impact tests on plain semi-porcelain household plates (Ware No. 2).

gained in the ultimate resistance to impact by increasing the thickness of the bottom of these plates above $\frac{1}{8}$ inch. However, the "starring" is also to be considered.

In all thicknesses except the greatest the effect called "starring" consisted of the cracking of the glaze on the bottom side of the plate. In the thicker plates the "star" penetrated the body of the ware. The lower curve in Fig. 1 indicates the impact at which this occurred in this ware. The blow required to produce "starring" increased with increase in thickness of the plate. The relation of these factors for this ware followed closely the parabola

$$y = 3x^{2.236}$$

in which y equals the impact energy in foot-pounds causing "starring" and x equals the thickness of the plate.

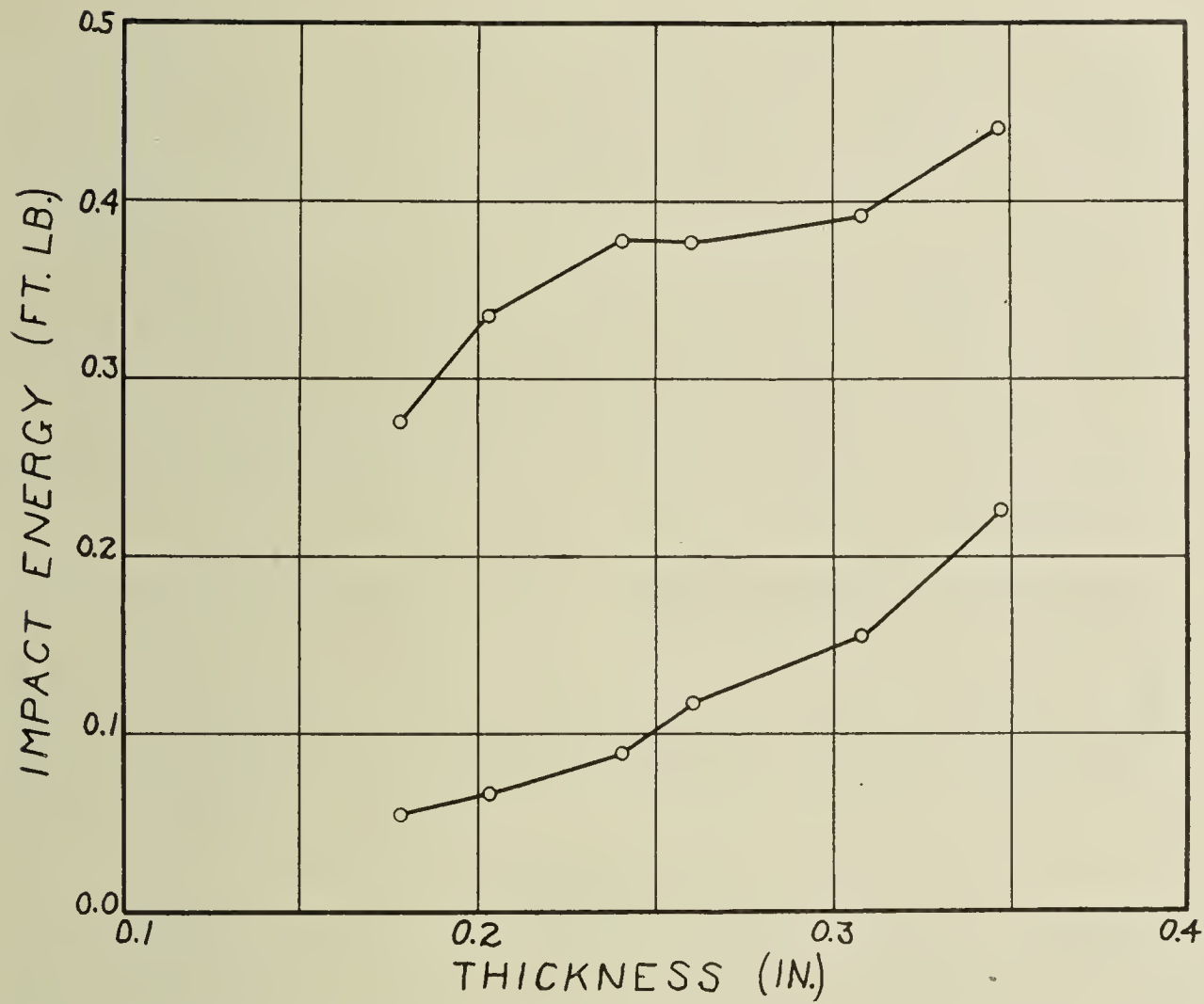


FIG. 3.—Results of impact tests on double-thick semi-porcelain hotel plates (Ware No. 3).

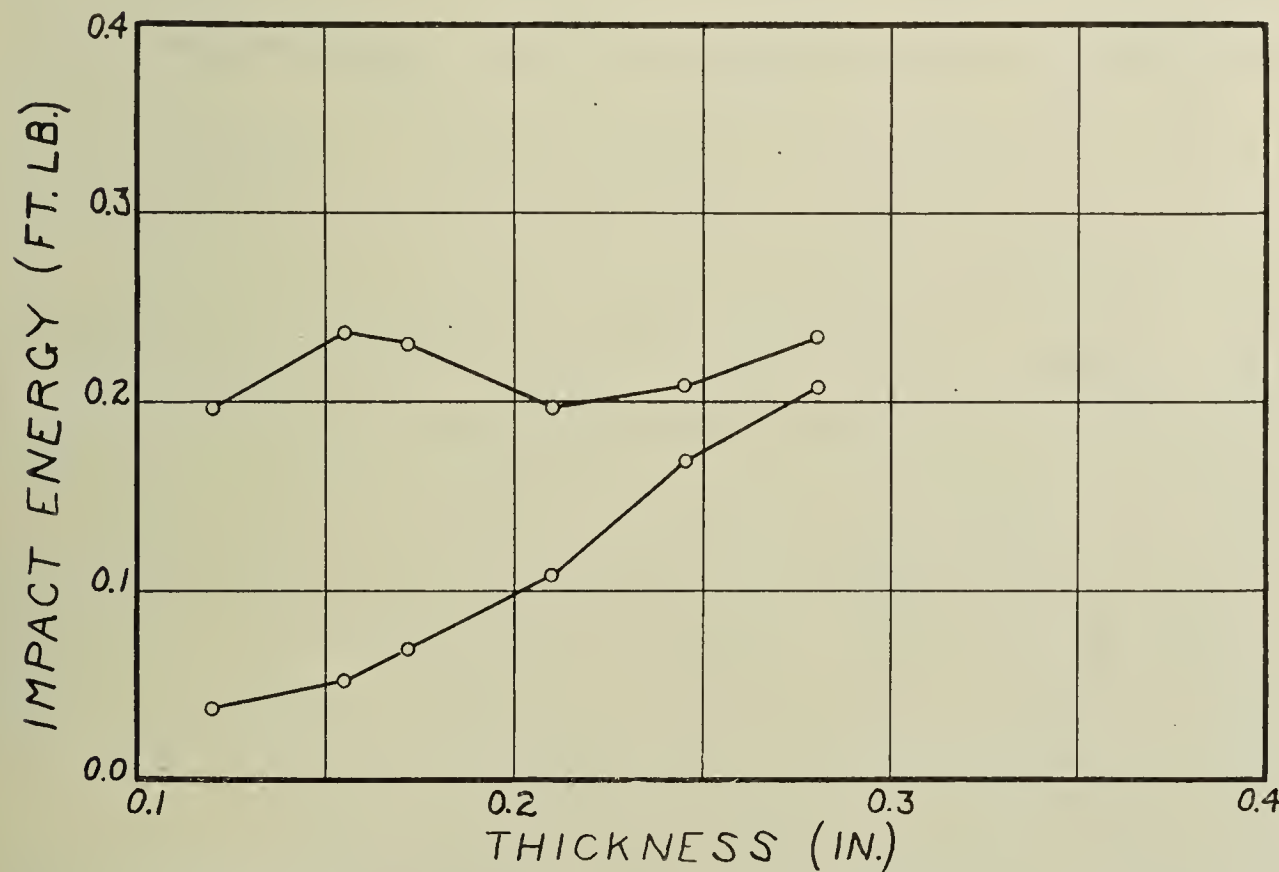


FIG. 4.—Results of impact tests on rolled edge vitrified hotel china plates (Ware No. 4).

Fig. 2 shows the average results of sixty plates of each thickness of a different brand of plain semi-porcelain household plates. Both the curve indicating the ultimate impact strength and that showing "starring" followed the same trend as those in Fig. 1 and the foregoing discussion of these results applies equally well to this brand with the exception that the parabolic equation would be somewhat different.

Considered collectively, the results on these two brands appear to check each other in regard to the impact-thickness relations.

Fig. 3 shows the average results on double-thick, plain edge, semi-porcelain hotel plates with very thick rims. About twenty plates of each thickness were tested.

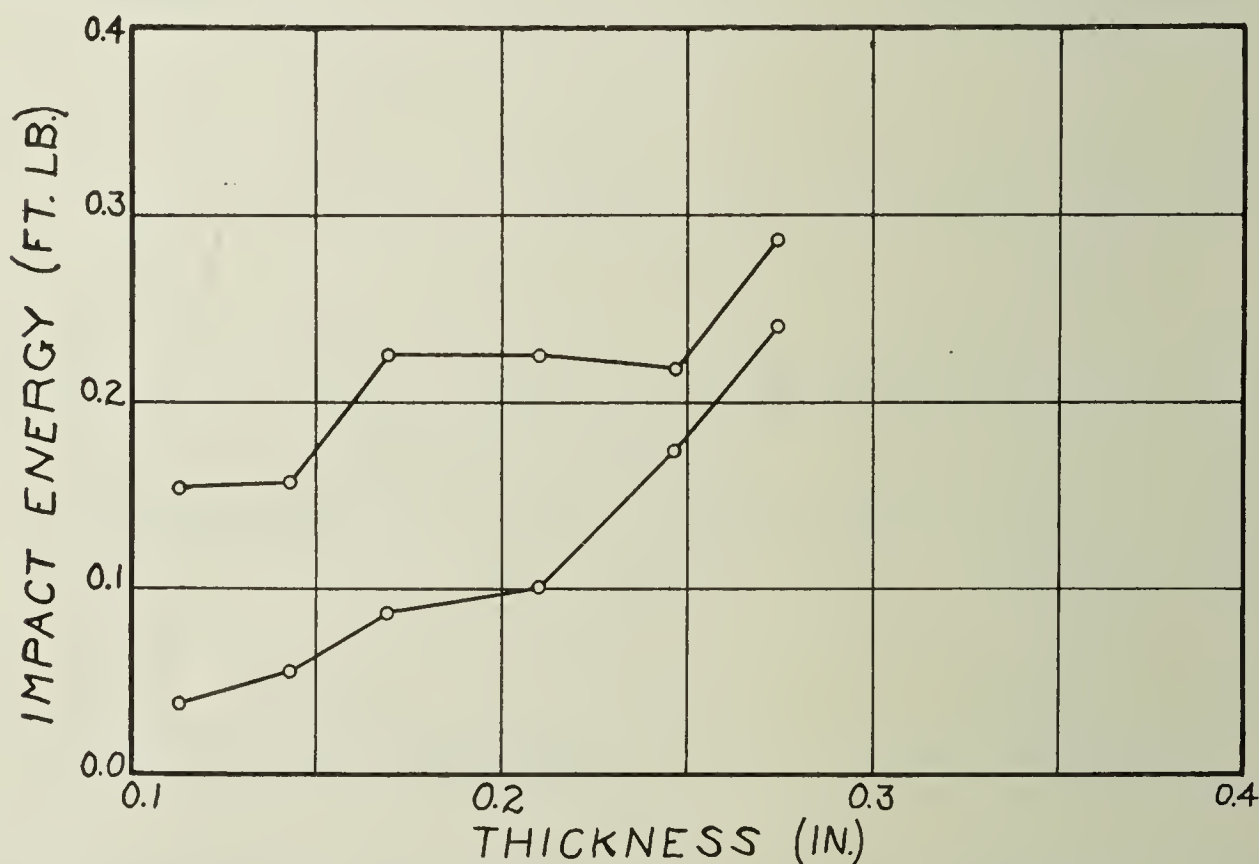


FIG. 5.—Results of impact tests on rolled edge vitrified hotel china plates (Ware No. 5).

While the curve showing the relation of thickness to the impact energy causing "starring" is very similar to those for brands 1 and 2, the curve denoting failure differs considerably. In general the resistance to impact of this type of plate increased with increase in thickness, although the effect was only slight between thicknesses of 0.24 and 0.31 inch.

The impact causing failure of these plates is much higher than any of the other types tested, which is probably due to the stiffening of the bottom of the plate by the very thick rim. This difference in design also probably accounts for the difference in the relation of the thickness to the impact causing failure.

Fig. 4 shows the results on one brand of vitreous hotel china of the ordinary rolled edge design. The lower curve indicating "starring" is a parabolic curve similar to those for the other brands of ware. The results

for impact failure of these plates were not consistent and the thickness of the ware appeared to have no regular relation to the blow causing failure. The thickness could be ignored in comparing results of impact tests on these plates of different thicknesses within the range in thickness in which they are ordinarily made.

Within the limits of commercial thicknesses these plates failed at a somewhat greater blow than brands 1 and 2, plain semi-porcelain household plates, but at considerably lower blows than brand 3, double-thick, plain edge, semi-porcelain hotel ware.

Fig. 5 shows the results on a second brand of vitrified hotel china rolled edge plates. In this case, as in the others, the impact causing "starring" increased with the thickness in an approximately parabolic curve. The relation of the impact causing failure to the thickness was more regular than in brand 4, and while increase in thickness increased the ability to withstand impact, it will be noted that within the range in thickness in which these plates are made commercially, the thickness had no effect on the blow causing fracture.

Summary

The impact force causing "starring" of seven-inch plates of all types tested increased with increase in thickness in an approximately parabolic relation.

Increase in the thickness of plain semi-porcelain household plates within the range in thickness in which such plates are made commercially had no appreciable effect on the impact causing complete failure of the plate. At greater thicknesses increase in the thickness did increase the ability to withstand impact at the center.

In double-thick semi-porcelain hotel plates the ultimate impact strength increased irregularly with increase in thickness and the blow causing failure was much higher than for the other types of plates tested, due to the bracing effect of the very thick rim.

The impact causing complete failure of vitrified hotel china plates did not appear to vary regularly with the thickness.

These results indicate that in comparing results of impact tests of this kind on commercial plain and rolled edge plates, small differences in thickness may be ignored.

In designing plates little is to be gained in resistance to impact as indicated by the Bureau of Standards test, by increasing the thickness within the commercial limits, but the resistance to "starring" is increased by increasing thickness.

The author wishes to thank Messrs. A. V. Bleininger, F. K. Pence, C. E. Jackson, James M. Smith and Thomas B. Anderson and the companies with which they are associated for contributing the sets of plates tested in this work.

SOME NOTES ON HISTORICAL AND MODERN DECORATIVE PROCESSES¹

BY FREDERICK H. RHEAD

ABSTRACT

A review of the best known ceramic decorative processes. The various processes are described and a classification is suggested for the different types. The decorative types dealt with are: 1. Incised processes. 2. Modeling. 3. Slip decorations. 4. Underglaze. 5. Polychrome Glaze Decorations. 6. Monochromes. 7. Lustre. 8. Overglaze Processes. 9. Ceramic Sculpture. 10. Architectural Terra Cotta and Faience. The general conditions involved in the production of ceramic wares in the craftsman's age and the present industrial age are described.

The possible field for research in ceramic decorative process work is so large that it would be impossible to cover the ground in a lifetime, even if one concentrated on a single process. In fact, the practical potter and the decorative man are seldom familiar with more than one or two methods of manufacture, and at the most, two or three decorative processes.

Manufacturers of clay products usually confine their activities to the production of individual types which may be classified into such broad groups as:

(1) **Refractories.**—Embracing the production of firebrick, muffles, crucibles, saggars, kiln fixtures, etc.

(2) **Industrial Porcelain.**—Covering such types as electrical and chemical porcelain, fixtures and utensils for various industrial purposes.

(3) **Stoneware.**—Including chemical and utilitarian stoneware; sewer pipe, etc.

(4) **Sanitary Ware.**—Bathroom, kitchen and lavatory equipment.

(5) **Earthenware and China.**—Table and general utilitarian wares.

(6) **Architectural Wares.**—Ranging from the ordinary building brick and the commercial floor and wall tile to the more or less elaborate terra cotta and architectural faience.

(7) **Art Wares.**—Including the various types of ornamental pottery used largely for decorative purposes.

The range appears yet more comprehensive when it is realized that each type requires entirely different manufacturing conditions, and its own particular class of organization, factory equipment, technical and practical attitude, type of labor, market and consumer.

A wide variety of clays are used, possessing many different physical properties, and varying in action according to their place in a particular composite body. The clays may be ground and washed, or they may be of course texture and altogether unrefined. They may be of different degrees of plasticity, and ranging from the exceedingly stiff pugged mixtures used in some machine pressed wares to the slushy consistencies used in some of the art pottery wares. They may be used in the form of moist

¹ Paper read during the Annual Convention, AMERICAN CERAMIC SOCIETY, St. Louis, 1922.

dust for floor and wall tile presses, and for electrical fixtures, or they may be used in the liquid state in consistencies varying from eighteen to thirty ounces to the pint.

Kiln temperatures in general practice vary from the soft faience limits of cone 05 or thereabouts to the porcelain and refractory temperatures of cone 16 and higher. Cone 9 or 10 is no longer the commercial limit. In fact cone 16 is the minimum temperature for certain industrial wares.

Considering the possibilities in ceramic decorative process work, the potter is always bound by temperature limits. Maximum temperatures of cones 1, 5, 10, 15, and 20, will each result in the production of technical types varying from the other according to the position the others occupy in the range. As the temperature limit is increased, the use of certain fluxes is lessened or discontinued, and others are substituted. The change is so complete that what may serve as a clay body at a low temperature may easily be adapted as a glaze at a higher heat; while a number of the higher temperature glazes now in use would in effect be opaque or translucent bodies in the lower temperature ranges. These conditions suggest the enormous number of variations and the differences in manufacturing conditions when the various ceramic processes are considered.

The art of the potter is simple as well as complex. It is full of contradictions. There are very few assertions or conclusions relating to ceramic work which cannot be debated or considered to have many interpretations. In its simplest aspect, and speaking quite broadly, one might say that the art of the potter consists in the molding of the plastic element to a required form, and the subjection of this form to sufficient heat to harden or crystallize the clay mass. This is much the definition that would be considered satisfactory to a superficial interest in the subject. A general knowledge of the commercial processes, and the ability to define these processes in concrete examples is evidence that the dealer and salesman are well read in their respective fields. To the manufacturer who is interested in the production and disposition of his goods, this interest concentrates on conditions surrounding one type. He knows the performance of certain kinds of equipment, of certain classes of labor, of market conditions pertaining to his own particular productions. The factory manager is in much the same position, and so are the specialists engaged in one class of work. For the craftsman, it is enough if he possesses the ability to execute a single type, working much in the manner of the medieval craftsmen, but taking advantage of such modern developments as the portable kiln which works much with the precision of the kitchen stove. There are many specialists who are well read on process work. But knowledge or intimacy of the various branches, or of any particular branch must be derived through practical experience with production. Any theoretical knowledge

must be supported or backed by activity which will successfully produce concrete results. A successful laboratory experiment will corroborate a scientific theory, but there still remains the very practical problem of large scale production within a definite cost limit, whether in the form of quantity units, or in regard to the individual size of the job, as in the case of a big architectural work.

An expert may know definitely that any particular process is entirely practical, he may possess knowledge to formulate a program, design equipment, and define conditions for the production, but unless there is also the ability to carry out that program, the ability that will anticipate unfavorable conditions, rather than deal with them as they arise, there is a serious lack of practical experience which should be present, whether it be possessed by the technical man or by the practical potter.

This lack of practical experience is one of the chief problems confronting the ceramic manufacturer today, and it is one of the reasons why he should exert every effort to bring about a condition where we will have industrial schools for training practical potters.

While this somewhat lengthy transgression might be thought to be foreign to the subject of this paper, its purpose is to bring to the attention of those who are interested, a realization of the conditions which must have existed in connection with the production of the types to be discussed; conditions which unfortunately do not exist in this country except in a few isolated cases. In reviewing the practical methods employed in the production of the various types, developments which have been possible only as the result of grinding and intensive practical research in each case, the modern practical ceramist will not only acquire a knowledge of his debt to the pioneers in the various fields, but he will (or should) learn something of the conditions necessary for the continuance of the various developments.

In attempting to review some of the processes practiced by potters of various countries and periods, I will not touch upon the preparation and manipulation of the materials except where there is a direct relation to the decorative process in question, but will describe the best known historical and modern types, using illustrations when these will clarify the point under discussion.

I divide my references into ten broad groups, as follows: (1) Incised, etched and carved processes; (2) modeled relief processes; (3) slip processes; (4) underglaze processes; (5) polychrome glaze processes; (6) monochromes; (7) luster processes; (8) overglaze decorations; (9) ceramic sculpture; (10) architectural pottery.

1. Incised, Etched and Carved Processes

It is obvious that all primitive processes would be simple in method. About all the primitive could do would be to scratch on the surface of the

form. That natural decorative instinct of the savage, an instinct that has almost been cultivated out of existence in this so-called civilized age, was always active and ever present.

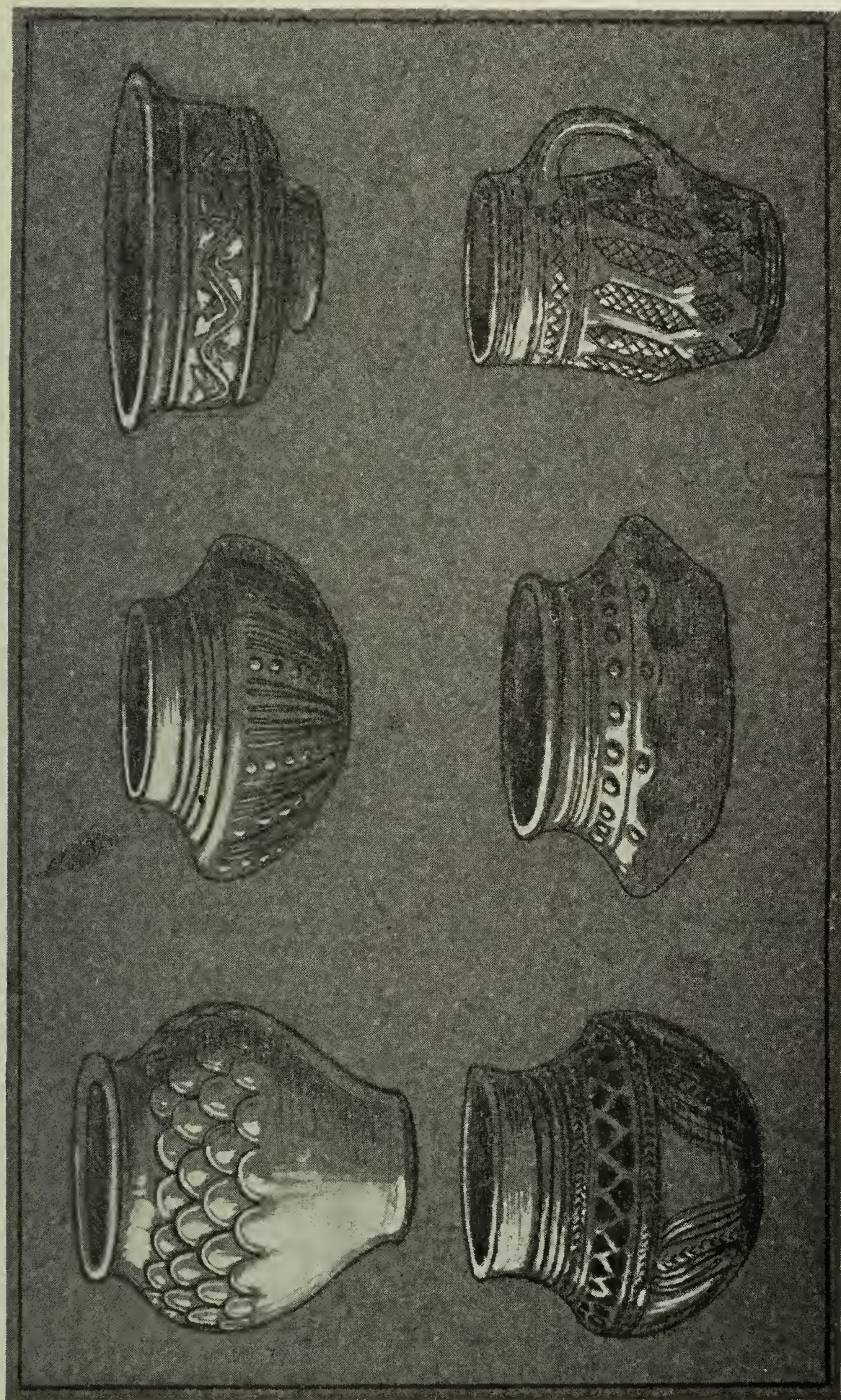


FIG. 1.—Early British pottery.

Upon the completion of the shape, the potter might be dissatisfied with the crudeness of the form, and scratch over the surface to divert the attention from lack of finish, or being satisfied with the result, would be

moved to carry the work still further, and so scratch whatever symbols or signs came to mind.

Whatever the idea may be, the means are primitive enough. A blunt pointed stick is used and the decoration incised upon the shape.

Plastic clay lends itself excellently to the incised processes. Quite elaborate designs may be worked out if the potter possesses a sense of design and is skilful in using the tool.

As clay varies in its working and plastic qualities, it follows that the texture of the clay would to some extent control the method and execution. Some clays can be incised while the clay is in a soft plastic condition, and with an ordinary blunt point, while other clays, porcelains for instance, are incised or carved while in a harder or less plastic state. Under such conditions tools made from Swiss files or old dental tools are used. For plastic surfaces, tools made from ordinary darning needles are most satisfactory. The point of the needle is inserted in a convenient handle, and the eye is sharpened around the edge. A well-made tool of this character will make a clear line without a ragged edge. The excised clay comes through the eye of the needle leaving a cleanly cut and delicate line.

There are three kinds of incised line: (1) The line made by pressing the tool to the soft plastic surface; (2) by dragging or pulling the tool over the outline, as in the case of the needle tool; (3) and the carved line executed when the clay object is almost or quite dry.

Types of Incised, Etched and Carved Processes.

- (a) Archaic pottery.
- (b) Early Celtic burial urns.
- (c) Indian pottery.
- (d) Carved Chinese pottery and porcelain.
- (e) European craft pottery.
- (f) Sgraffito. (Combination of the slip and incised processes.)
- (g) Incised glaze process. (A hard enamel or fusible slip is applied to the clay form, and the design is incised and cut through the outer coat to the clay body.)

2. Modeled Relief Processes

Every potter knows, or should know, the important place the modeler should occupy in most potteries. He is responsible for the execution of all ornamental relief, and the form to which this is applied.

His treatment of a particular subject will determine the character of mold to be used. It is the tendency in commercial practice to simplify mold construction. Articles such as teacups, pitchers, coverdishes and teapots, which used to be cast from molds having separate parts for the handles and spouts are now cast with these already on the shape. In such branches of ceramic work as architectural faience and terra cotta, the modeler is really a sculptor, while in the utilitarian ware branches he is a

highly skilled mechanical craftsman. In commercial practice, an inefficient modeler may cost a concern large sums annually. Lack of mechanical accuracy, disregard of the current contraction scale and warpage



FIG. 2.—Ancient Chinese pottery.

curves, are contributory causes to unsatisfactory product and loss which could be directly traced to the original model providing there is present the practical knowledge that can trace and check such faults.

Original Development of Modeled Decorations.—As the primitive became more familiar with his material, it would occur to him that he might add clay to the surface instead of incising or carving it from the shape. The first developments were most probably combinations of the two methods such as adding dabs or buttons of clay to emphasize the incised places. As the early potter realized the possibilities of work in relief more elaborate specimens were executed. The Grecian and Roman terra cottas, and some of the Chinese pieces of the Han and Sung periods are typical examples.

Plaster molds were not in general use until about 1750, although they are said to have been used in Italy in the sixteenth century. Before this molds were made of porous terra cotta and various metals. The primitives used fruit forms and baskets for molds. Because of the harder substances formerly used in making molds, many of the early pieces are remarkably clear and sharp in relief.

Eler's Ware (English).—Reliefs were obtained by pressing seals or intaglio molds to the surface of the ware. Thin slabs of soft plastic clay were placed over the desired spot, the stamp pressed against this, and the rough edges cleaned off. At this period such stamps were extensively used especially in connection with red wares and stoneware.

Wedgwood Ware.—Wedgwood reliefs were pressed from porcelain molds and then applied to the surface of the ware. The shape would be made on the wheel and afterwards turned on the lathe. Wedgwood developed this combination of the two processes to a very high degree. A shape would be put on the lathe half a dozen times to attain a finish which could not be completed in fewer operations. The shape would be roughly turned, then inserted in a hollow form for support while the foot was being turned. The piece would then be dipped in a dark blue or some other colored slip, dried to a firm plastic condition and again put on the lathe to be polished and to have the lines, borders, and other details executed. Wedgwood used wheel dies called runners which were pressed against the revolving shape, and any number of mechanical devices for obtaining various results.

When the shape was completed the clay reliefs were pressed from the porcelain dies and applied to the form, using water as the adhering liquid. Every detail in this process requires a high degree of mechanical skill especially so, when it is realized that in the final operation when the figures are applied on the ware, the piece must still be in the plastic state.

Palissy (1510–1589).—Palissy often produced reliefs from molds which were cast from metal or natural objects, a method resulting in clear and

sharp reliefs often mechanical in effect. Palissy's reliefs were nearly always in the mold and not applied to the ware itself as was done by Wedgwood and the Eler's.

German and French Stoneware (1400–1800).—Examples of careful potting and mechanical finish. Much of this ware was made in a stoneware body well washed and often finely screened, generally finished in salt glaze. The reliefs were both incorporated in the shape mold and applied by means of stamp dies. Factories producing such wares were located at Grenzhausen, 1780, Siegburg, about 1570, Limburg, 1580, Cologne, 1600, Bayreuth, 1600 and in other places in Germany, and at Saint Porchaire (I allude to the Henri Deux ware made between 1524 and 1537, and called by the French: *Faïence d'Oiron*), Beauvais, Apt, Avignon, 1650 to 1780 and Paris, 1560.

3. Slip Processes

As the craftsmen interested in sculpture would naturally lean toward relief decorations, so the potter interested in painting would seek out possibilities in flat surface decorations. The primitive had no further resources so far as his palette was concerned than the various natural colored clays at hand. As his wares were burned at a comparatively low temperature he had few problems of contraction to contend with. He selected his colors, generally a palette limited to red, black, ocher and white, and applied these directly to the surface.

With the developments in process came more refined methods. Other colors were added to the palette by staining the white and lighter colored clays with calcinations of mineral oxides, and naturally the technical field became more involved. Decorations subjected to a high degree of heat became more subject to the law of contraction. If the applied slip did not shrink evenly with the ware, it scaled off either before the ware was dry, or after it was fired. Color combinations had to be carefully thought out with the chemical action in mind. Chrome green slips could not be mixed with yellows or browns containing iron if the greens were to be retained. In what is known as the Rookwood type of slip painting, where an iron yellow glaze is used the greens are obtained from cobalt combinations and are consequently quite blue in hue until the yellow glaze is applied and fired.

Some of the modern slip processes are very elaborate, and require a high degree of skill in execution. *Faïence*, earthenware, stoneware and porcelain bodies are equally appropriate for these processes, and the potters of the various countries have produced fine examples of slip decoration in all these bodies.

Types of Slip Processes.

- (a) Primitive slip processes using natural clays.
- (b) Slip processes of the Toft school.
- (c) French barbotine processes.
- (d) European craft pottery, Black Forest school.
- (e) Rookwood school.
- (f) Copenhagen and Sèvres school porcelain.
- (g) Pâte-sur-pâte, Sèvres and Minton.

(a) **Primitive Slip Processes.**—Examples of slip decorated pottery have been produced in all countries where pottery has been made. But the slip decorations of the British under Roman influence (A. D. 117–138), the Anglo-Saxons about 580, and from the date of the Norman conquest to the sixteenth and seventeenth centuries (Toft and Eler's school), are probably the most typical.

(b) **The Toft School.**—The Toft school is one of the most interesting of the early influences. Thomas and Ralph Toft (1660–1676), lived in a period when the local craftsmen were beginning to realize the possibilities in ceramic decorative work. With few mechanical devices, a practical knowledge limited to throwing and turning, and the other elementary processes of the time, and without any foreign decorative influence, the wares of the Tofts and their followers are distinctly English in type. The quaint conventionalizations of historical and local personages are very cleverly spaced, and the inscriptions and ornamental details naively reflect not only the personal interest of the craftsman in his work, but the spirit and atmosphere of the period.

The ware, as suggested, was made on the wheel, and the decoration applied mostly by means of a contrivance that looked something like a teapot with a small narrow spout. The slip was mixed to a thick flowing consistency and poured out in the form of a fluid outline.

A skilful user of this instrument can draw an outline of varying thickness and make all manner of shapes and spots, sometimes covering large surfaces.

The palette was generally limited to two or three colors, and the ware finished in a raw lead glaze stained with iron.

(c) **French Barbotine Processes.**—The French art potters produce cleverly executed naturalistic decorations in colored slips. The backgrounds were brushed over the surface of the ware, and the technique was identical to that used in oil painting. In some instances, the ware was baked before it was decorated, and in such cases a calcined slip was used as a base for the various colors. A number of English factories, Leeds, Wardles, Doultons and Minton, also produced similar types.

(d) **European Craft Pottery.**—These were developments involving combinations of the early slip processes. Backgrounds were applied by

means of the blowing bottle, a contrivance similar to the teapot contrivance used by the Tofts, and by dipping. Some of the decorations were applied by means of the so-called tube process. This tube is a development of the

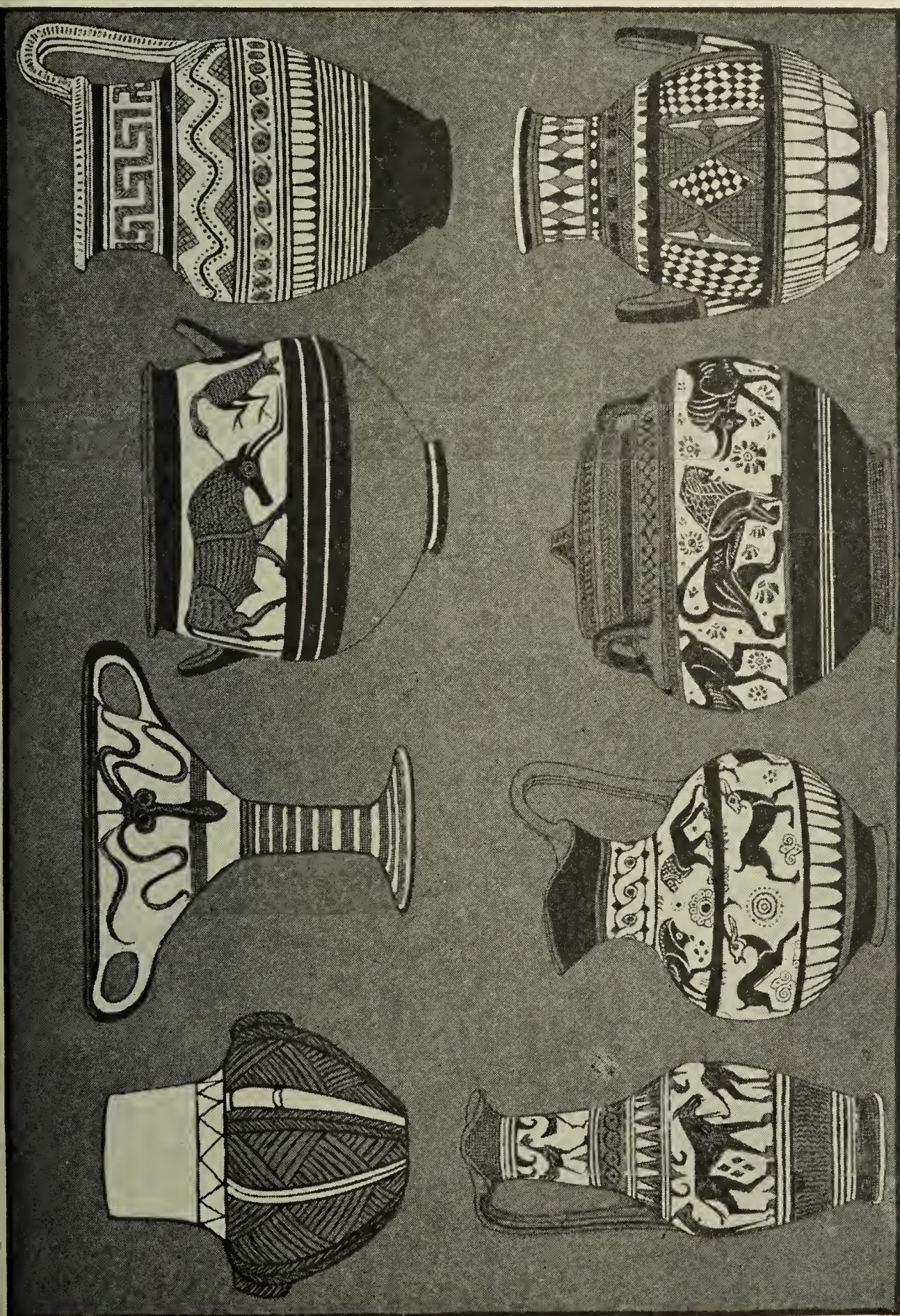


FIG. 3.—Early Grecian pottery.

blowing bottle and consists of a rubber bag, or a collapsible tube to which a glass or metal hollow point is attached. The bag is filled with slip and a slight pressure to the bag or tube produces a raised line corresponding to

the size of the opening of the point. This process has been used with considerable commercial success in connection with the production of both earthenware and tile. Conventional designs were also painted on the ware in colored slips. The small art potteries in Devonshire, England have produced interesting examples.

(e) **The Rookwood School.**—The French naturalistic slip painted wares seem to have been the inspiration for the early Rookwood pottery although there was obviously the policy and intention to develop a characteristically American product. The majority of the decorations were originally naturalistic in style, but the Rookwood decorators inclined toward a more highly finished technique rather than the bristle brush manipulations of the French and English slip painters. While the boldness and dash of some of the French examples may be admired, there is no doubt that the extreme delicacy of the Rookwood technique was more appropriate for the smaller pieces. Some writers have thought that Rookwood has been influenced by Copenhagen and contemporary pottery of like standing. The reverse might be just as likely because Rookwood has been developing her original processes for more than forty years, and has exhibited abroad at most of the foreign expositions since 1880, while the naturalistic slip decorations in porcelain of the Copenhagen school were not in vogue previous to the Paris Exposition of 1900. It seems more correct to assume that the best of the Chinese and Japanese porcelains have influenced not only Rookwood, but also the big continental factories producing naturalistic slip decorations in faience and porcelain.

(f) **Copenhagen and Sèvres School.**—These organizations also produced naturalistic slip decorations possessing a high degree of finish, but porcelain bodies were used, resulting in a transparency and delicacy not possible in earthenware or faience. Some of the examples are so delicate in treatment, and low in relief that they look more like underglaze painting on the biscuit. The colors are rich, but low in value because of the fact that the wares are fired to a high temperature, in some cases to cone 17. The Rorstrand pottery of Sweden has also produced fine examples in this type.

The best works of these concerns, together with those of Rookwood can undoubtedly stand side by side without losing in comparison with the finest pieces of Kozan, Seifu, and other great Japanese pottery decorators.

(g) **Pate-sur-Pate.**—A process, which superficially speaking would be included in the modeling group, except that it is essentially a slip process and not modeled in the plastic sense of the term. It is executed exclusively in porcelain clays. A slip ground is applied, and the design, generally a figure subject, is drawn on the surface. A white or contrasting colored silhouette of slip is painted within the outline, making the lowest plane in the relief. This is scraped perfectly level, and the next highest plane

painted over the silhouette, scraped and graduated to the lower level, and so on until the highest planes are reached. The process involves both brush and tool work. The slips are naturally opaque before firing, and where the decorator desires transparent effects, he must use careful judgment and great skill in tooling his planes.

L. M. Solon of Sèvres, and later at Mintons earned an international reputation with his works in *pâte-sur-pâte*. The writer's father, Frederick A. Rhead, and a pupil of Solon produced a number of important pieces in this process at Mintons and later at Wedgwoods.

Taxile Doat, of Sèvres, one of the greatest decorative ceramists of today, used this process for a number of his more ambitious works. This country, and particularly St. Louis, is very fortunate in possessing some three hundred pieces of Doat's work.

4. Underglaze Processes

In dealing with descriptions of processes, one is confronted with problems of definitions and classifications due to misunderstanding and confusion resulting from misnamed and misleading trade names which have come into common use. In this country, underglaze work is commonly understood as referring to slip-painting, while in other countries it refers to decorations applied to the biscuit surface.

Slip decorations are done on the clay with stained slips, while, as stated, underglaze decorations are done on the biscuit surface with calcinations of the metallic oxides. At the lower temperatures, ranging to cone 7 or 8, the colors may be very deep and rich, and fairly wide in variety of hue. As the temperature increases, the yellows and reds are eliminated, leaving a working palette consisting mainly of blues, grays and greens. The colors are finely ground, and used with water and some gummy medium as in water color, or with turpentine and fat oil as in oil painting. There is practically no limit to its possibilities in technique. An artist can paint in the broadest possible manner, or he can do miniature work. For the commercial processes, printing, stamping with sponges, stenciling, lithography and even photography have been used in connection with underglaze color work. The Staffordshire printed dinner wares are typical examples of the commercial processes, while the Copenhagen, Delft, Italian and Chinese underglaze decorators have shown something of the possibilities in decorative work.

Types of Underglaze Decoration.

- (a) Grecian vases.
- (b) Persian faience.
- (c) Italian, Spanish and Mexican faience.
- (d) Japanese and Chinese porcelains.
- (e) Staffordshire printed wares.
- (f) Modern underglaze decorations.

Grecian Vases.—Perhaps these vases should be included in the slip painting group. But speaking from a ceramic painter's point of view it is an underglaze process. All slip work, except the highly stained high temperature porcelain decoration, is more or less in relief, that is, the color is applied as a body as in oil color, and not as a stain as in water color. While underglaze colors may be quite heavily applied, the color is generally flat. The Grecian vases are flat in decoration, and if duplicated today, there is little doubt that underglaze colors would be used. The pottery of the Hissarlik class and found in the northern islands of the Greek Archipelago resembles both in shape and decoration some of the early Indian pottery of this country. The Mycenaean, Dipylon, Phaleron and Corinthian wares are more elaborately decorated, the latter having borders of real and imaginary animals and birds. Some of the examples show a distinct Egyptian influence. While the body generally was a soft porous earthenware, numerous examples of porcelain have been found of the period of the seventh century B.C.

The black-figure period (sixth century B. C.) and the red-figure period (fifth century B. C.) both furnish magnificent examples of design and ceramic decoration. The fourth and third centuries B. C. marked the decline of Greek vase painting.

Persian Faience.—There is a wide difference of opinion in regard to the classification of Persian pottery. The issue has become confused by the fact that various writers on ceramics have expressed definite opinions which have not been backed by adequate technical and practical knowledge. Certain writers base their assumptions according to the original composition of the body, irrespective of the possible changes in the same body when it is subjected to varying degrees of heat. An example of ceramic work made from kaolin, feldspar and silica is certainly not porcelain until it is subjected to a temperature high enough to make it vitrified and semi-transparent. A composition that may be quite suitable for a faience or earthenware, may easily be a true porcelain if fired to a high enough temperature. While all clay compositions will not become semi-transparent, except possibly, when the mixture is melted to a viscous or fluid condition, most of them can be brought to a vitreous and non-porous condition. This may properly lead one to assume that porous or absorbent bodies are immature bodies, and that a finished ceramic work should be classified according to its final physical characteristics and not according to its original formula content.

Classification.—While the following classification may be questioned, the given terms are at least applied with some knowledge of the technical and physical elements involved.



FIG. 4.—Mexican majolica.

Terra Cotta.—Unglazed, opaque, porous or absorptive red or buff bodies.

Types.—Early primitive potteries, Grecian potteries, Tanagra figures, early Danish figurines, red floor tile, architectural wares.

Faience.—Glazed, opaque, porous or absorptive red or buff bodies decorated or otherwise.

Types.—Primitive, Persian, Italian, continental and English craft wares, Leeds, early Rookwood art wares, Rookwood and American encaustic architectural wares.

Earthenware.—Glazed, opaque, porous or absorbent, white, blue-white or cream, decorated or otherwise.

Types.—English and American non-vitrified dinner wares, Ruskin and similar art potteries.

Stoneware.—Glazed and unglazed opaque vitrified bodies, white or any color, more commonly buff or gray. Decorated or otherwise.

Types.—Early English salt glazed wares, German stoneware, Lambeth, English and American opaque vitrified dinner wares, chemical stoneware.

Porcelain.—Glazed or unglazed, semi-transparent, vitrified or semi-vitrified bodies of any color, decorated or undecorated, irrespective of kiln temperature.

Types.—Early Egyptian, Persian, Chinese, Japanese, English bone china, Belleek, Sèvres and similar continental types, continental and American semi-transparent table wares, chemical and electrical porcelain.

Such a classification would define pottery that is opaque and porous as either terra cotta, faience or earthenware, that which is vitrified and opaque as stoneware, and that which is semi-transparent as porcelain.

Persian Underglaze Decorations.—Underglaze decorations were applied directly to the body, and also over a white engobe. The combination of the rich alkaline glazes, somewhat heavily applied, with the sandy bodies, together with the brilliant contrasts in color resulted in a type that has never been equaled for richness and delicacy in effect. Even the best examples of other types of faience seem hard and uninteresting in texture when placed in direct contrast with fair examples of Persian faience. Some of the wares closely resemble the Chinese productions, and there is little doubt that the Chinese workmen who visited Persia exerted an influence for a considerable period.

Italian, Spanish and Mexican Underglaze Decorations.—Except for the difference in style and decorative treatment, it would be difficult to distinguish between the underglaze wares of these countries. Under this classification, I do not refer to the tin enamel or majolica processes which generally include the use of underglaze colors. I include only those wares decorated directly on the clay or bisque surface and glazed with a white or colored transparent lead or alkaline glaze.

The Italian type includes the so-called Mezza-majolica, and more slightly incised wares finished in underglaze colors, and the modern craft pottery. Cantigalli is a well known type, although a considerable part of this product is decorated over a tin enamel. Most of the true underglaze work in Italy seems to have been done previous to the best majolica period,

1500–1560, and later than the eighteenth century. Most of the pottery of Spain, Portugal and Mexico was also of the tin enamel type, but all three countries produced, and do produce, underglaze decorations on the biscuit.

Chinese and Japanese Porcelains (Chinese).—While the periods of the various styles and types of Chinese porcelains can approximately be determined, many experienced authorities admit their inability to tell whether certain examples were made during the period they are supposed to represent, or later. Examples of the Ming dynasty were certainly reproduced during the later periods and up to the eighteenth century, while during the Ming period, most of the earlier porcelains were reproduced.

Although this fact makes the actual identification of many examples difficult if not doubtful, the various types and processes can definitely be ascribed to the period of their origination and highest stage of development. Whether a particular example actually was made in this period, or later, is another matter, and does not concern the present discussion.

The first Chinese underglaze processes were without doubt the cobalt blue decorations which have been the inspiration for much of the continental blue and white wares of Delft and other potteries, and the English printed underglaze wares. Exquisite examples of these blue and white wares were produced under the Ming dynasty, and under the Ch'ing dynasty during the K'ang Hsi, Yung Cheng, and Ch'ien Lung periods. The highest stage of development was reached during the K'ang Hsi period. The designs were outlined with masterly precision and daintily shaded with lighter tones of the same blue used in the outline.

The backgrounds were variously treated. In some examples, the white ground of the porcelain was left untouched. In others it was broken by cross hatching as was done in some of the Hawthorne decorations, and again, the background was filled in with solid blue. Other colors and also colored glazes and enamels were used in combination with the cobalt blue, the more brilliant of these being applied after the underglaze decoration was glazed and fired. (The latter will be treated under the headings of Polychromes and Overglaze decorations).

The decorative motifs were as varied as their processes. Flowers, birds, animals, landscapes, figures, mythological and symbolical subjects, naturalistically and conventionally treated, were arranged over the most complicated and intricate areas not only with a consummate knowledge of design, but with a true craftsman's understanding of the possibilities and limitations of his material.

The Chinese ceramic artists (and they were artists in the highest sense of the term) developed a national and individual style which, with the Grecian, Persian and Italian potters formed the four great classical types which have influenced the ceramic work of all the other countries.

Japanese Underglaze Porcelains.—Burton gives the following interesting account of the introduction of porcelain-making in Japan: "The pioneer of Japanese porcelain was Gorodayu Go-Shonsui, who spent five years in China learning the art at Ching-te-chen. Returning to Japan in 1515 he made blue and white porcelain with imported Chinese materials; but as he was unable to find the necessary clay in Japan, his success was only temporary and left nothing but the knowledge of painting in blue under a glaze. The requisite materials, however, were discovered in the province of Hizen by a Corean named Risampeï, about the year 1605, and forty years later two potters named Tokuemmon and Kakiemon, with some help from a Chinese, developed the art of painting in enamel colors." The Japanese followed the Chinese processes and decorations quite closely and except for the difference in style, and for the more delicate, and perhaps effeminate (though none the less skilful) technique of the Japanese, it is obvious that the Chinese productions were the predominating influence in connection with the earlier and much of the later Japanese development.

There is little doubt that some of the softer effects were obtained by painting directly on the clay surface, and baking the pieces before they were glazed. When this is done, the colors, particularly the cobalt blues, will slightly stain the body and soften the edges of the masses of color.

Burton also states: "The Kyoto potters did not turn their attention to porcelain until the end of the eighteenth century. Eisen was the first and he was followed by Mokubei, Rokubei, Eiraku, Dohachi and a number of other clever potters. The Seto factories, destined to be the most productive in Japan, owe their knowledge of porcelain-making to Kato Tamikichi, who penetrated the secrets of the Arita potters in the first decade of the nineteenth century."

Staffordshire Printed Wares.—Sadler and Green of Liverpool, England, are supposed to be the originators of printing on pottery in 1752, while Holdship and Hancock both claimed to have invented the process at Worcester in 1756. Brongniart states that printing was done in Marieburg in 1760. Whatever these facts may be, it is definite that Sadler and Green did develop the process independent of any other influence, and that Staffordshire potters, Wedgwood included, sent their wares to Liverpool to be printed and returned later to be glazed and fired. A number of the potters of this period made desultory attempts to execute the entire process on the factory, and Adams of Cobridge finally succeeded about 1775, after which time, Baddeley's, Spode, Wedgwood, Davenport, Ridgway, Enoch Wood, Minton and other manufacturers produced the printed wares which were the vogue for over one hundred years.

While ceramic printing is a comparatively simple process, it involves a considerable amount of preparatory work. The original design is carefully drawn and engraved in facsimile on a copper or soft steel plate.

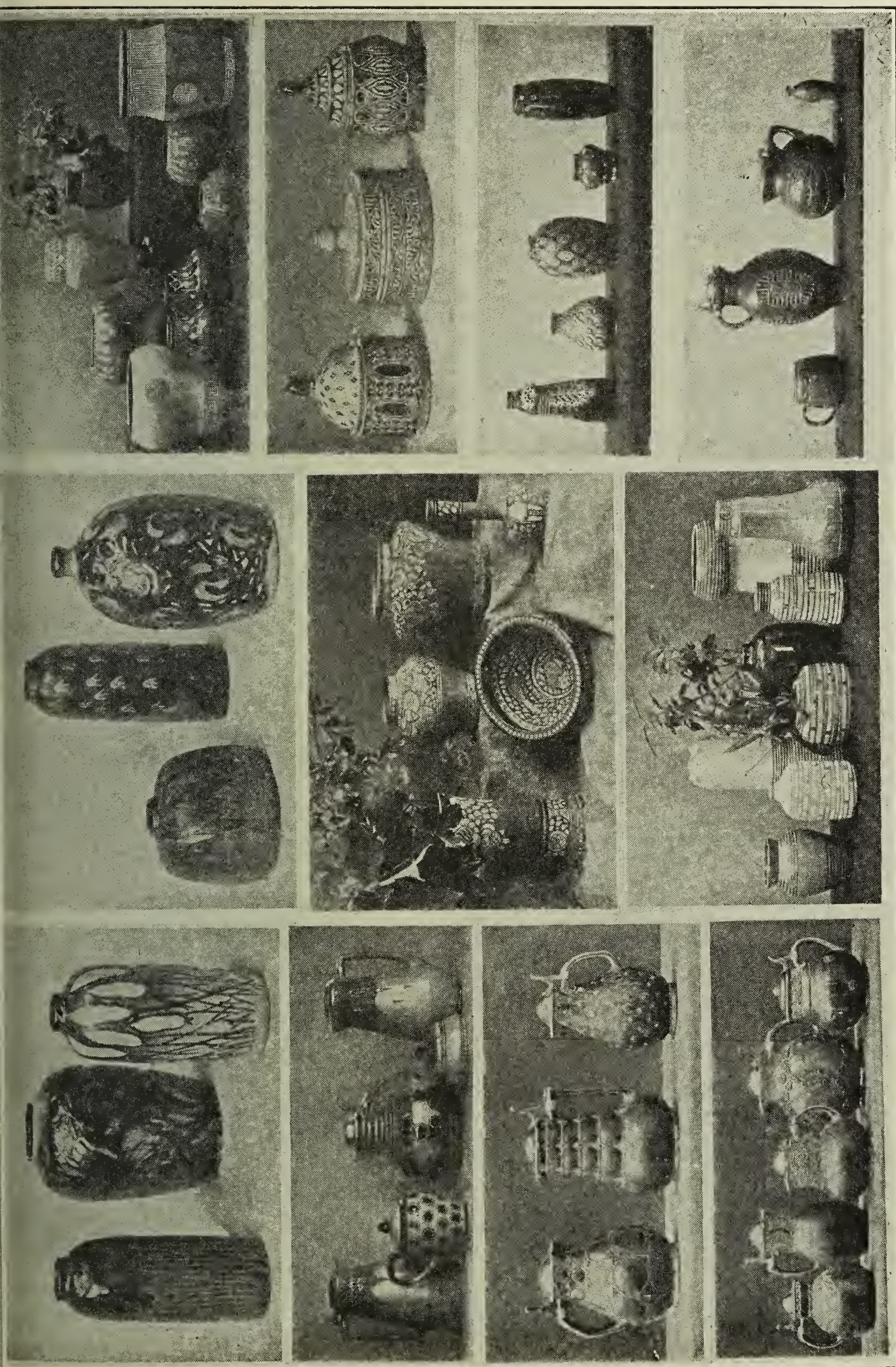


FIG. 5.—Modern German and Austrian craft wares.

The actual printing is done on a soft semi-transparent rice paper and transferred from this to the ware before the print is dry. The first printing was done with the roller hand press, but later a mechanical press was developed which printed the designs in continuous sheets which were cut up into individual patterns and arranged over the ware. Although the commercial and artistic possibilities have by no means been exhausted, the lithographic process has (temporarily, we believe) almost entirely replaced printing from copper plates.

The early printed designs were both oriental and pictorial in character, and as is usual during the development of a new decorative process the ornamentation was profuse rather than restrained. A dinner plate would have a heavy floral border, and the center would have a view of some public building or some historical scene.

The historical subjects included both domestic and foreign incidents, relating to peace and war, and portraits of famous characters. The early patterns were usually printed in blue. About 1830 other colors, black, brown, lilac and pink were used, and still later, the designs were considerably simplified, engraved mainly in outline and filled in with a number of other colors. However, the blue and white wares were the most popular at the time they were produced, and it is this class which is most valued by collectors of Staffordshire printed ware today.

Modern Underglaze Decorations.—In discussing modern underglaze productions the reviewer must take into consideration the influence exerted by the government art schools of the various countries. Previous to 1890 the manufacturer (with a few notable exceptions, such as Mintons) was content to ring the changes on the various historical types according to the pressure of competition and the demand for a change in style. Decorations were mainly naturalistic, or they were mechanical adaptations of foreign styles. But it is evident that the activities of the English Art Schools together with the active interest of such men as De Morgan, William Morris, Walter Crane, Coleman and others would result in a realization of the need for national decorative types. The English school of design was the predominating influence in Europe at this time, and quite creditable work was done by the art school students who were also apprentices in the factories. Underglaze decorating requires no equipment except the biscuit ware, colors and brushes, so the pieces could be taken to the schools, decorated under the direction of the design masters, and then glazed and fired at the plant. Here was a coöperation between school and factory that was bound to reflect to the benefit of the industry. The Paris Exposition of 1900 brought together the ceramic works of the various countries, and in the decorated types, a fair proportion were executed in underglaze colors. The English wares were of the Morris-Crane school decorated on a white body, or buff and terra cotta bodies using white as a

acifier. The French were at this time running wild with their abominable L'Art Nouveau decorations, while the Germans were just developing

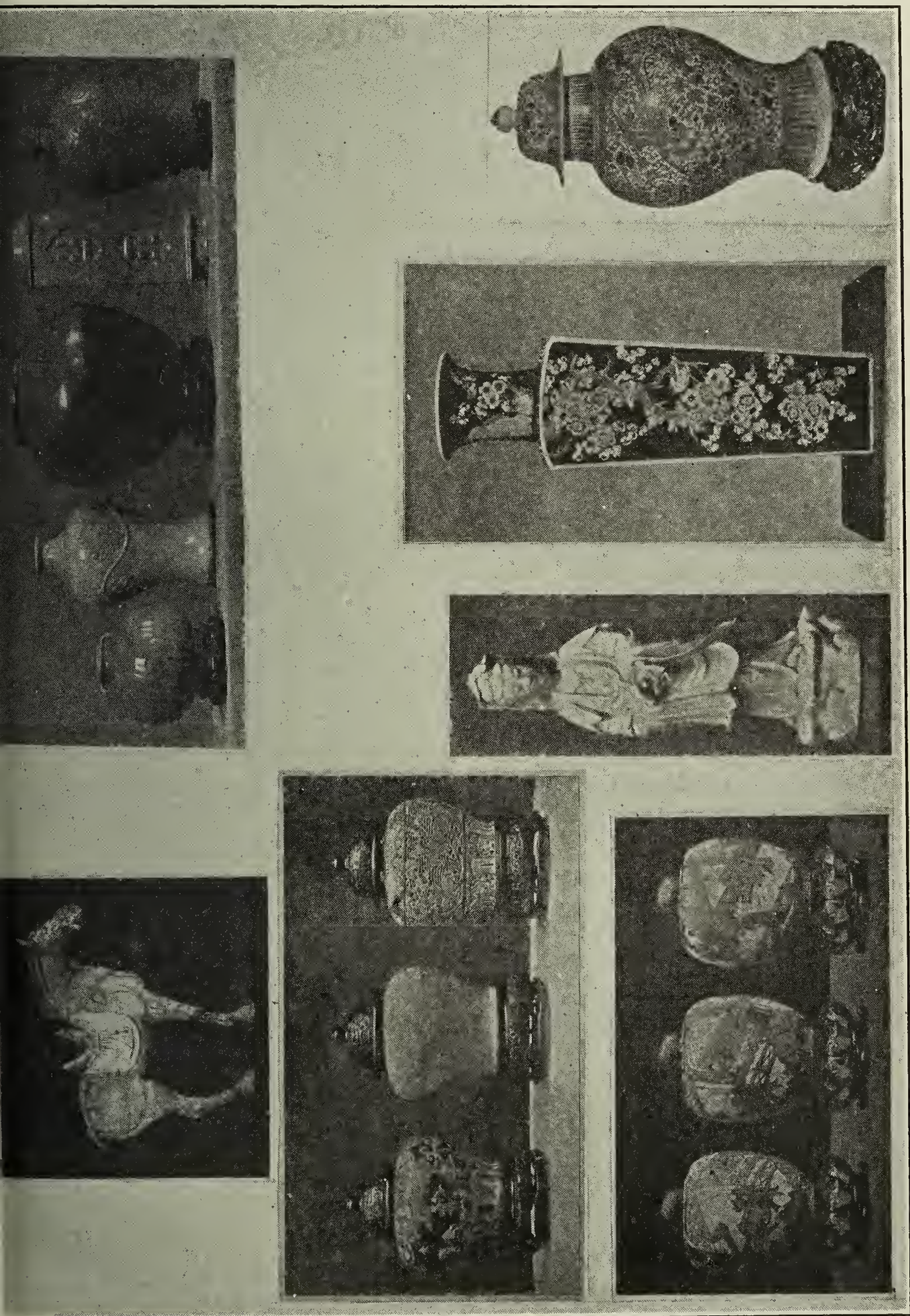


FIG. 6.—Chinese pottery and porcelain of various periods.

their heavy, stupid and elementary checker-board conventionalizations. Compared to the bulk of the latter productions, the primitive and even the archaic potters were masters of shape construction and ceramic design.

Notwithstanding these abortive and strained attempts at originality enough really good work has been done to show that the continental potters are really interested in the possibilities in ceramic decoration. Such men as Professor Max Lauger in Germany, Karl Klaus, Ernst Wahless and Professor Frommell in Austria, Arnold Krog of Copenhagen, Wallander of Rorstrand, Sweden, Laconte of Delft, Kok of Rozenburg, and Maurice Dufrene of France, however, are notable exceptions who have done much fine work in the underglaze, and other processes. F. A. Rhead, the writer's father, produced a big series of underglaze decorations for some of the leading art potters and tile manufacturers in Staffordshire.

5. Polychrome Glaze Processes

The polychrome glaze processes may be divided into the following groups:

(a) **Painting over Modeled Surfaces.**

Types.—Ming, Della Robbia, Palissy, Minton, English commercial art wares misnamed majolica, and American modeled matt glazed wares in colors.

(b) **Flat Glaze Decorations with a Flat Outline.**

Types.—K'ang Hsi, Japanese, Persian, Modern, Rhead Pottery, California

(c) **Flat Glaze Decorations with a Raised Outline.**

Types.—Ming, Japanese, Minton, Wedgwood and Moorecroft (England) Continental and American craft wares.

(d) **Flat Glaze Decorations with Incised or Sunken Lines.**

Types.—Japanese (Seifu), American Art Wares, Tile, American Encaustic Tiling Co.

(e) **Painting over Unfired Glaze.**

Types.—Persian, Italian Majolica, Delft, Mexican, American Encaustic Tiling Co.

(f) **Decorating with Juxtaposed Glazes of Different Colors and Textures.**

Types.—Modern tile decorations, American Encaustic Tiling Co.

(g) **Splashed, Mottled and Blended Glazes of Different Colors and Textures.**

Types.—Chinese, Japanese (various periods), French studio potters, Sèvres Copenhagen, English (Ruskin, Pilkington, Minton, Leeds, Bretby Bernard Moore, etc.), American (Binns, Rookwood, Robineau, Robertson, Walrath, and a number of craft potters).

Modeled Surfaces.—In the mind of the layman, painted glaze decorations are often associated with the majolicas of the Della Robbia type to the exclusion of other groups which should be included under this classification. When the potter commenced to use colored glazes, he would naturally try them out on whatever type of pottery was available whether it would be suitable for the particular treatment or not. We have examples of polychromes of most of the early potters of various countries, but nearly always over modeled surfaces.

With many glazes it is a delicate proposition to attempt to paint on flat surfaces. Aside from the tendency of such glazes to flow, there is the



FIG. 7.—Persian luster wares.

additional tendency to run into those glazes in juxtaposition, a property which has been used to great artistic effect in many types of ware. Not all glazes will flow, however. Tin enamels, tin, zinc, some of the alumina and fritted matts, and a number of the higher temperature felspathic glazes do not as a rule flow very much, and a number of these may be applied in juxtaposition, or on the top of one another without either flowing, or losing the detail of the design. But the lower temperature lead and alkaline glazes, the crystalline series, and most of the transparent enamel flow very readily, especially when applied on upright surfaces.

The method generally adopted for the painted glaze processes is to provide some means of separating or confining the various masses. In some of the early modeled wares, the glaze was either applied so thin that there was not enough mass weight to flow, or there was a total disregard of the flowing properties of the glazes. There are examples of Ming porcelains of both types, and the early English Whieldon ware shows an effective use of two or more colors flowing into one another over modeled surfaces.

While as stated, tin enamels do not readily flow, the Della Robbia modeled their panels with a definite glaze treatment in mind. The various masses and details were clearly and beautifully defined, and so arranged that a deep blue of a drapery, for instance, could not easily flow over, or stain the white enamel of a face, hand, or foot. In some of the Ming pieces, the glazes would be applied in such a manner that they would slightly overlap one another, resulting in soft and indefinite edges to the masses of color.

The English commercial colored glazed wares were decorated with washes or applications that were not heavy enough to flow to any great extent. The American art potters cleverly avoided the undesirable effects of flowing when heavy masses of glaze were required, as in the case of many of the matt glazes, by arranging their designs vertically over the shapes. The vertical leaf designs of Grueby, Rookwood and Teco are typical examples.

Flat Outlines.—The potters of the K'ang Hsi period used an outline of underglaze color or metallic stain. There are a number of possibilities in connection with flat outlines. Not only can various colors be used for this purpose, but different effects can be obtained by varying the thickness or width of the outline. The masses of glaze may be applied just to the edge of the outline, or, if the line is wide enough, the glaze may slightly overlap the edge, but not enough to touch the adjoining mass of color. An outline may be clear and definite, or it may be soft, and become partial or almost wholly absorbed by the surrounding masses of glaze. Black oxide of manganese finely ground makes one of the most satisfactory outlines for such work. It is a soft but lustrous brownish black, and when solidly applied will hold quite a heavy mass of glaze in position. An inter-

sting effect is also obtained by adding about ten per cent of black oxide of copper to the manganese. This will result in a slight greenish stain along the edge of the outline, and it is most effective where light color schemes are used.

Raised Outlines.—A raised outline may be produced in the mold of the piece; it may be applied with a brush (a rather slow and laborious method), or drawn over the shape, or surface, with the tube which was described in the section on slip processes. In the two latter methods, the outline may be in any color, but in the molded line, it would be of the same color as the clay body. In tile, and faience wares, where a dark molded line is desired, a red body is often used. Where there is considerable background, the piece may be dipped or sprayed with the background glaze which is scraped off those portions requiring another color. These details are then applied with a brush. When the decoration is broken up over the surface with little background space, the brush is used altogether.

Many fine examples of garnitures, and other ornamental pieces were decorated with glazes of aubergine, green and blue, and the masses separated by means of a white raised line, by the potters of the Ming and early Tang Hsi periods.

The Japanese have also used this process. The raised line in the above instances was produced with a brush, and by the very laborious method of carving away the background with the exception of the raised boundary around the masses of glaze. Judging from the rounded and spontaneous quality of the outline of some specimens it is fairly definite that an instrument similar to the slip tube was also used.

The raised outline work has been a popular commercial art process for a number of years. Mintons used it with good artistic effect, and another of Frederick Barnard, the well-known illustrator of Dickens, introduced this process at Wedgwood, and later at McIntyres of Cobridge, England. Moorecroft succeeded Barnard at McIntyres and produced some cleverly designed semi-naturalistic decorations. The continental potters have used this process extensively, and it practically became standard decorative type among the tile manufacturers in England, on the continent and in this country.

Incised or Sunken Lines.—The incised line has been more often used directly over the clay surface, in connection with the sgraffito processes, or with the slip processes.

Because of the tendency of many of the glazes to flow, the ceramic craftsman has avoided sunken lines in connection with polychrome glaze processes. But curiously enough, an incised line is one of the safest outlines for this purpose. A glaze that is excessively fluid will flow to the edge of a sunken line, and then stop unless the glaze is too heavy, or the kiln

temperature too high. For this reason, and also because floor decoration should be flat, the incised outline is most appropriate for polychrome treatment for floor tile, and it is being generally used with commercial and artistic success by the tile manufacturer.

Painting over Unfired Glaze.—Glazes which can be used as unfired backgrounds for decoration are generally such non-flowing types as tin enamels, non-crystalline matts, and the higher temperature feldspathic



FIG. 8a.—Italian faience underglaze painting over tin enamel.

matts. Transparent glossy textures, raw lead, fritted lead and alkali glazes are almost entirely flowing glazes, and as such cannot be used for backgrounds, or for decoration over other unfired glazes if clear details are required. As a rule, if a glaze is suitable for a background, a color pale made up of the background base glaze is also suitable for the applied decoration. But this does not mean that various types of glaze cannot be used on the same piece. For instance, a vase or tile painted

can be glazed all over with a green tin enamel, and after the design has been sketched or stenciled over the unfired surface, the colored glazes, which may include colored tin enamels of the same type as the background glaze, matt glazes and even transparent glazes may be applied in such a manner that the original detail will be retained after the piece is fired. It is possible to obtain clear and sharp detail as well as soft blended effects. Glazes of soft rich texture can be applied over harder and lesser flowing glazes, or the reverse, with excellent artistic results.

If soft readily flowing mixtures are used, the detail will almost entirely disappear because the applied glazes will be absorbed into the background; or, in the case of an upright shape, the decoration will run down the piece,



FIG. 8b.—Modern English luster wares.

forming a streaked effect which will be more or less blended according to the softness of the glazes and the kiln treatment.

Generally speaking, glazes which mature at the same temperature should be used for the same decoration, although a decorator with sufficient knowledge of his material can successfully use glazes of widely varying types and degree of maturity on the same work. Or, for instance, a cone 10 felspathic matt may be applied over a cone 3 tin enamel if the applied masses are not too large to become partially or wholly fused into the background mass at a cone 3 temperature. In using glazes of a wide range in temperature, the lowest in range should be the background glaze, and the firing temperature adjusted to this particular glaze. If a cone 1 glaze is

used over a cone 8 background, the temperature required to mature the background will in most cases burn up the decoration.

It is well to bear in mind these conditions because many of the interesting effects by the early potters were obtained by means and combinations which would not be considered practical or possible by the technician of today. While an industrial process must exclude as far as is possible many variable elements which can to an acceptable extent be controlled by a skilful craftsman, it must also be remembered that the orientals were not technical men as we understand the term, yet we have produced few ceramic works which can compare with those of the potters of Persia and China.

The Persians decorated over an unfired glaze, but they used underglaze colors for outlines and the sharper detail. Copper green, cobalt blue, iron and manganese browns would be used as stains for the overglaze which would be floated or tinted either before or after the underglaze treatment was applied over the background glaze. Sometimes the completed decoration would be given a thin coat of transparent glaze which would increase the brilliancy of the color and texture. In such instances, the decoration consisting of colored glazes and underglaze colors would be sandwiched between an opaque enamel background and an overglaze of transparent glaze.

The Italian majolica of the Gubbio type was decorated with underglaze colors over the unfired tin enamel, with an occasional overlay of transparent glaze. In modern practice this process has been confined to work on flat tile. One method which has been found practical for quantity production is to stencil the glaze decoration directly on the clay unglazed tile, afterwards dipping it in the background glaze, which in this case would be transparent or semi-transparent.

Except where simple treatments are concerned, decorating over unfired glazes is essentially a craftsman's process, and while it has great artistic possibilities a considerable knowledge of technique is necessary to obtain reasonable and consistent results.

Decorating with Juxtaposed Glazes.—There are two methods of applying glazes in juxtaposition. One is to dip the piece all over in the background glaze and then scratch out the decoration which is to be filled in with the other glazes; and the second method is that where the design is drawn over the shape, and the background and decoration applied with a brush.

Tile and flat surfaces are most appropriate, and as with the process just described, the glazes used must be those which will not too readily flow or run into one another.

Splashed, Mottled and Blended Glazes.—Splashed and mottled effects were, originally, undoubtedly the result of the manipulations of the early

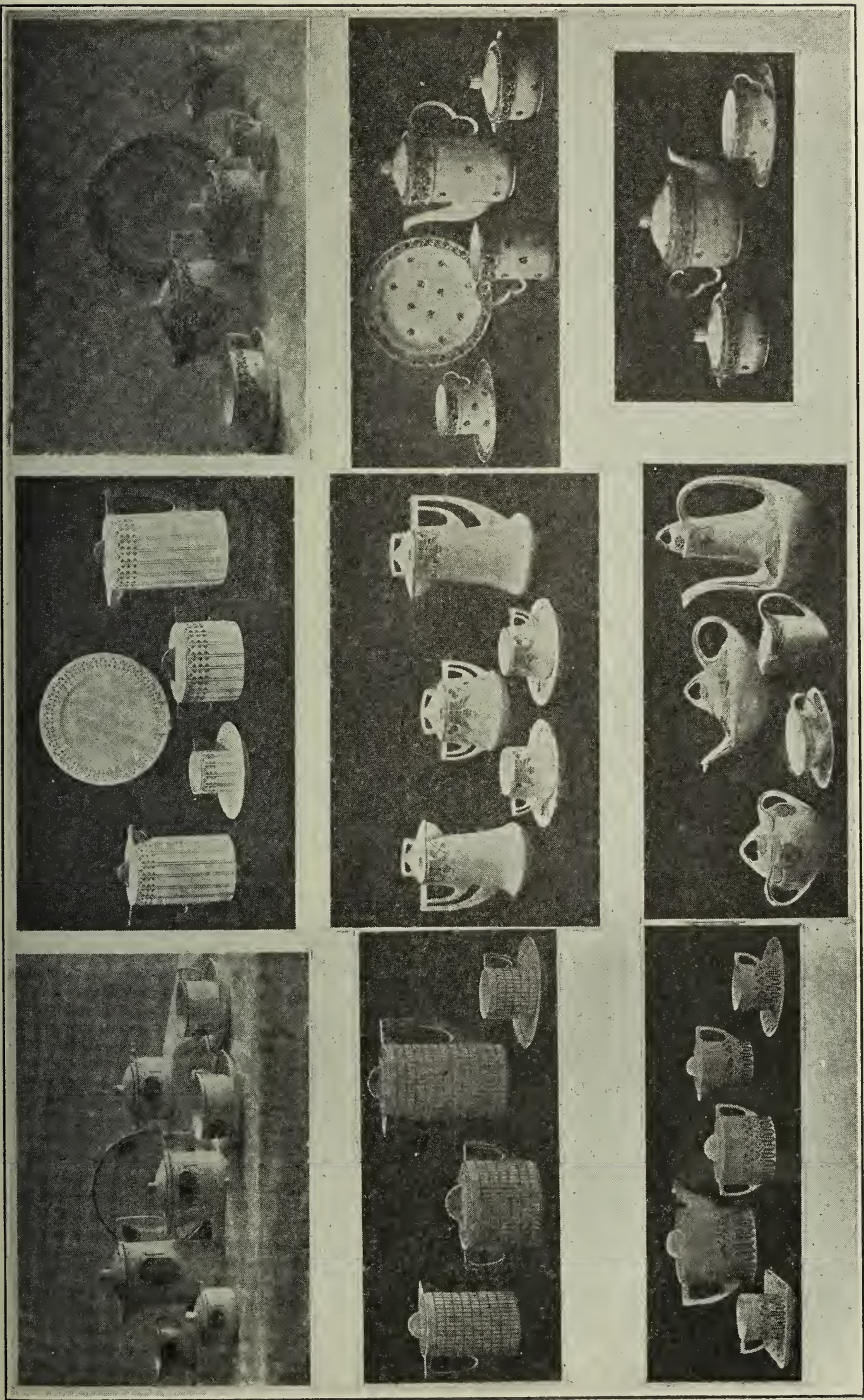


FIG. 9.—Modern German and Austrian tablewares.

pottery in doctoring those monochromes which were unsuccessful in the first fire. Most of the early Chinese pieces, for instance, were made on the wheel, often requiring considerable work. If for any reason a second application of the same glaze would not correct the defect, a glaze of another color would be splashed over the surface. In some cases where different colors would be used for the inside and outside of a vase the inside color would run over the edge and blend into the outside color and thus suggest possibilities for further development. The method of manipulation depended on the type of glaze used. Readily flowing glazes would suggest bolder treatments than those where non-flowing matts and enamels were used. In the former case, the unfired piece would present an altogether different appearance to the finished result. A flowing glaze that is sponged or splashed around the top of an unfired glazed piece will run all down the shape if the application is heavy enough. The glazeur can produce an approximate effect with some degree of certainty, but he cannot exactly reproduce a definite marking.

With non-flowing glazes, however, his conditions are subject to a greater degree of control. With atomizers of various sizes, or by spotting with his brush, he can mark or soufflé over a matt or enamel with copper, manganese or any of the metallic stains or even with glazes, and be reasonably sure that the effect will be retained after the piece is fired.

Practically speaking these processes are very simple, and while interesting effects are comparatively easy to obtain, it requires an artist to produce really beautiful and altogether satisfactory results.

6. Monochromes

It will be conceded by most collectors and connoisseurs that the most beautiful individual pieces, and certainly among the most prized are the monochromes. They certainly are the most difficult to produce. A skilful glazeur will cheerfully attempt a complicated piece of decorative glazing and be reasonably sure of a creditable result. But in attempting a series of monochromes he is never sure that he will get fine textures, or unblemished surfaces. Throwing and turning, pressing and casting, each have their particular body faults which may not be visible if the surface is broken up with decoration, but which may be plainly seen on a monochrome. The possible glaze faults are innumerable. Careless, or unskilful preparation of the glaze, the wrong method of application, imperfect firing, all contribute to the unsatisfactory result, or in other words, it is the perfect coördination of all the elements concerned that produces the perfect piece. The potter is often asked why he cannot, or does not produce examples in plain glazes that are as fine as the monochromes of the later Ming, or K'ang Hsi periods. Broadly speaking, the answer lies in the fact that we are living and working in an industrial age, while the ear-

pottery lived in the craftsman's age. It is true that we have craftsmen who are doing sincere and earnest work. But these men are not as skilful as the early potters. They did not go through the severe apprenticeship

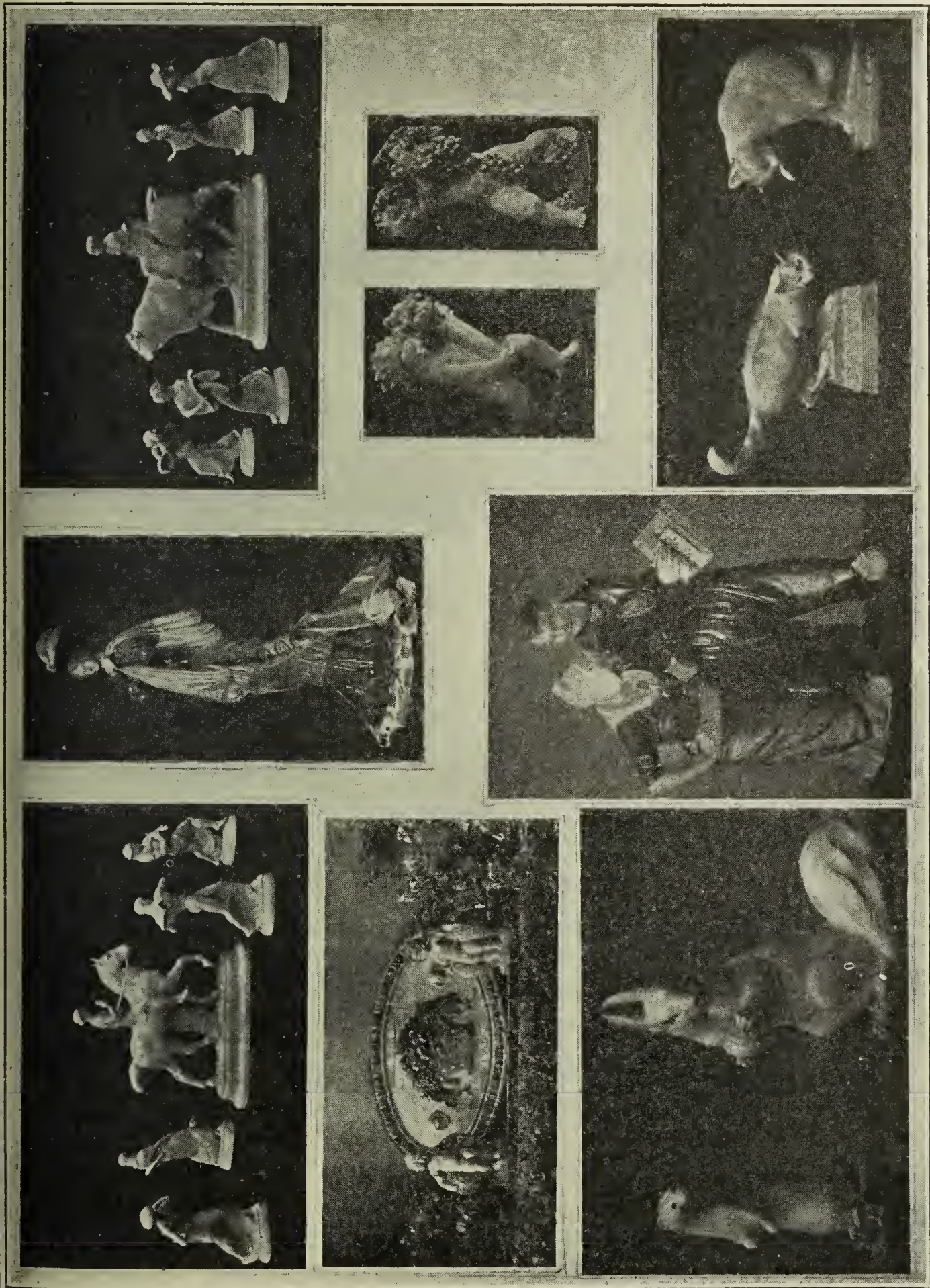


FIG. 10.—Modern faience and porcelain figurines.

that was compulsory during the best periods of ceramic development. In this industrial age, we have been trained to believe that the actual making of a clay form consists of little more than the mere pouring of slip

into a hollow mold, a process occupying a few minutes at most. If the piece is made on the wheel, it is either a process which must more or less compete with other commercial processes, or if the potter is a craftsman operating his own studio, he either does not possess the high degree of skill or he is obliged to turn out so many pieces per day irrespective of the degree of finish attained. The modern potter in making his shapes, does not give anything like the same amount of thought and study in regard to their construction as was customary among the early potters.

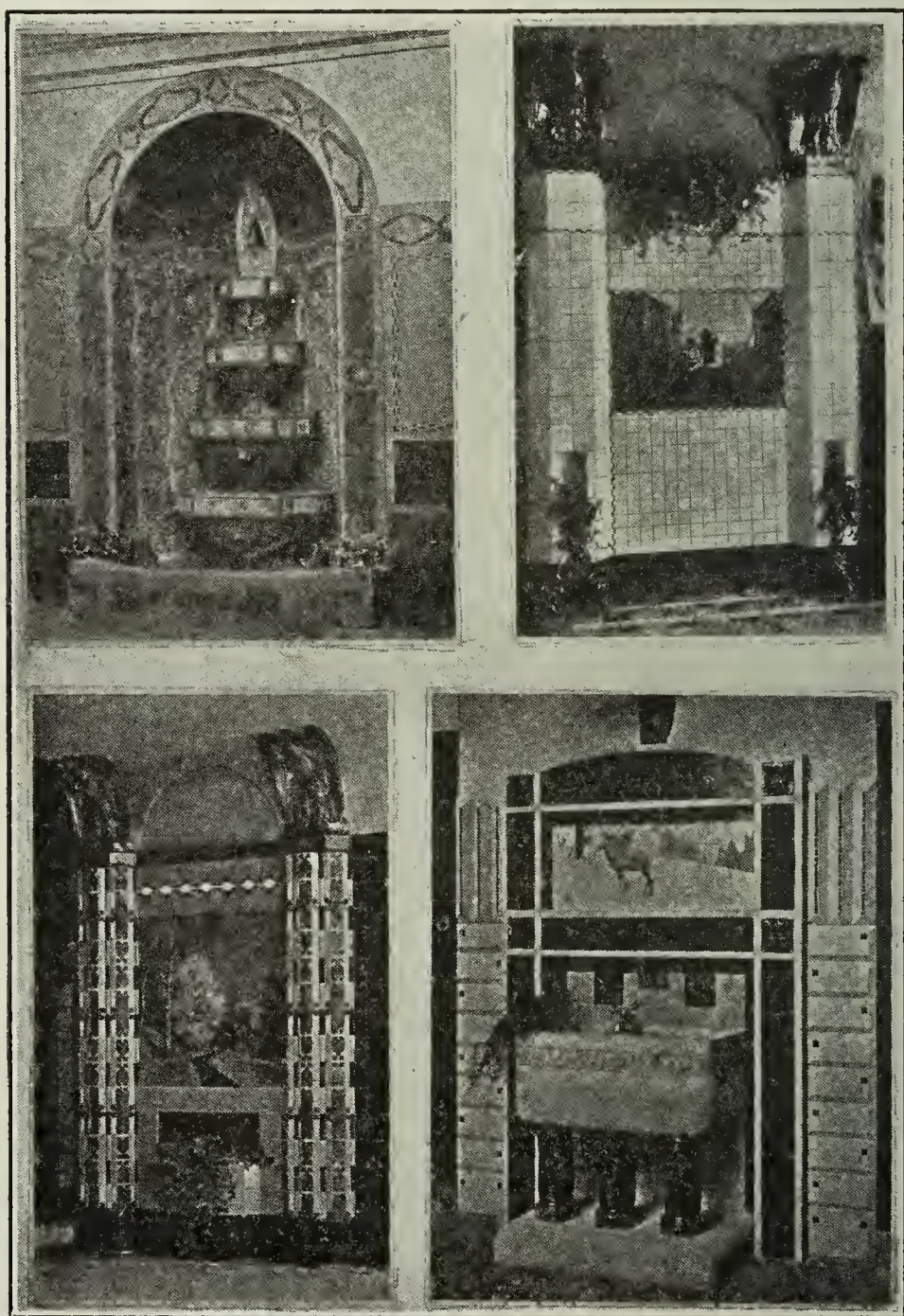


FIG. 11a.—Modern German and Austrian tile and architectural faience.

The two great ceramic shape construction developments are readily distinguished in the Grecian vases and in the Chinese vases, two totally different types, designed altogether under different conditions. The former were practically geometrical constructions, if we are to accept the analysis of Professor Hambidge in his scholarly attempt to discover the technical methods of the Greek designers (see the "Dynamic Symmetry

of the Greek Vase," by Jay Hambidge), while the Chinese vases were wheel manipulations of potters who were guided by an unerring instinctive taste for beauty of contour and form.

The Grecian vases are the forms of the sculptor and the architect, while the Chinese vases are the shapes of the true potter. Both are beautiful and perfect, but the latter are the logical and natural products of the potter's wheel, in fact the shapes could not have been originally developed by any other process. The Chinese potters gave the same care and study

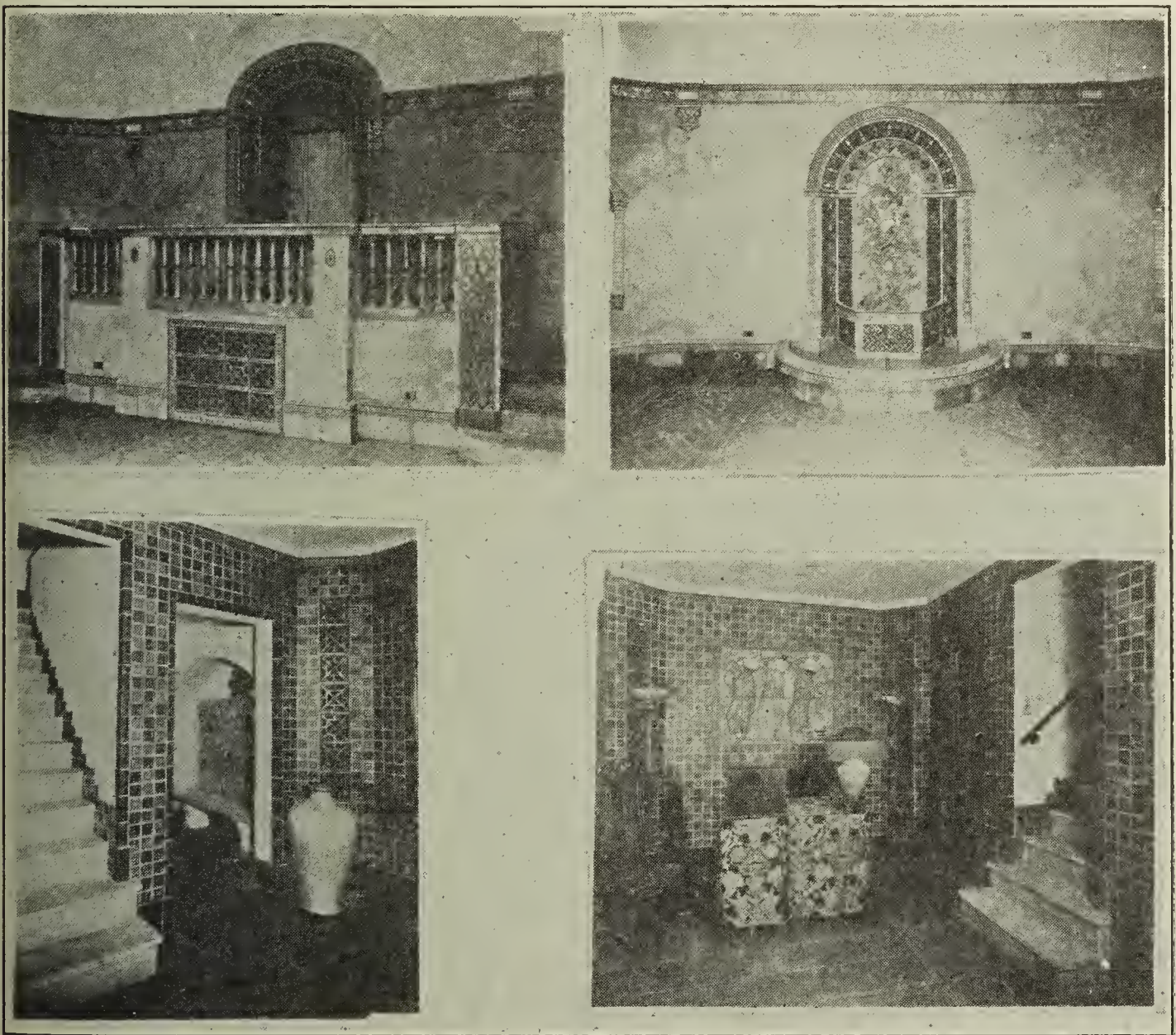


FIG. 11b.—Modern American architectural faience. American Encaustic Tiling Co.

to the glazing of the vases as they did to the making of the shape itself. It was not a matter of simply dipping the piece in the glaze tub, and scraping or cleaning off the base rim. Each piece received individual attention. If a flowing glaze was to be used, the amount of flow was fairly accurately estimated, and the glaze applied with a brush, heavier at the top, shoulders, and over any projecting place from which a certain amount would flow. The pieces revolved on a wheel while they were being glazed. From a craftsman's point of view, a glazed piece was a work of art even before it

was placed in the kiln. Dipping is a purely commercial process. It is the logical glazing process for industrial work, but however skilful a dipper may be, and however much care he may give to a series of monochromes, he can never attain the same quality of finish or control that is possible by brushing or spraying. Any potter or craftsman who has practiced both methods to any considerable extent can testify to this. Of course careful glazing by either the brushed or spray method is rather slow and laborious work compared to dipping. On the other hand, painting is slow and laborious when compared to photography and printing. If there are potters and art ware manufacturers who cannot easily accept these statements, let them take one or two of their best plain glazed pieces to the Boston or Metropolitan Museum and compare them with typical K'ang Hsi and Ch'ien Lung monochromes, taking note of their purity of form, beauty of finish, quality of texture, and richness of color. These qualities were not accidental, neither were they freaks of the fire. They were the result of hundreds of years of earnest development and concentration. With these facts in mind it is not difficult to realize why even an average bit of Sung, K'ang Hsi, or Ch'ien Lung will realize hundreds of dollars while a modern monochrome at fifty dollars is a rarity, or almost an impossible marketing problem.

I know of no modern factory or studio producing monochromes as finely finished or as beautiful in texture as the latter Ming, and K'ang Hsi yellows, turquoises, rusts, flambés, and others of the copper series, blacks, whites and a number of others, although the Japanese have produced some finely finished single glaze pieces. The Chinese as a rule confined themselves to mirror glazes, but they have produced surfaces of varying texture. Their iron rusts are often quite matt, and beautifully smooth to the touch. There are a number of beautiful matts, some of them having the texture of old parchment, eggshell, and others of the fruit skin variety. To properly classify glazes in regard to texture and color would be a big job. A collection of cabinet pieces of every possible variety would fill a large room. Considering the broad groups, we have white, black and colored glazes, which sounds like a simple and definite classification. But I have seen fifty different whites in one collection of Blanc-de-Chine glazes, all lighter in color than ivory or cream. The same might be said for the blacks. One could produce blacks for a hundred years and produce an amazing variety of texture and hue. Very few ceramists are aware of the possibilities in connection with combinations of metallic stains when used in proportions of ten per cent and over. I have dabbled with blacks for nearly ten years, and I know the subject is an inexhaustible one. Then consider the subject of texture. The first glaze developments concerned protective coverings for the clay surface. Then came transparent and opaque glazes of various colors. Developments of freaks of the fire and

speculative formula mixing accompanied rational glaze construction. Crackle glazes, a development of underfired felspathic enamels, flambés, a development of uncertain firing conditions, rusts and crystalline textures, developments due to the overloading with metallic oxides or experimenting with new materials have all contributed to present accomplishments and to the realization of new possibilities.

With all our present knowledge in ceramics we know very little about the monochrome and very few of us know how to make them.

7. Luster Processes

Most of the luster processes depend on the reducing atmosphere for the development of the iridescent surface and color. A typical method would be that revived by Massier. An alkaline tin glaze would be employed and matured in an oxidizing temperature. The glaze may contain copper, or a combination of metallic oxides. The fired piece is then decorated or splashed with a mixture of ocher, or combinations of other earths, and copper, silver and bismuth, with vinegar as a medium, and then subjected to a reducing atmosphere.

On coming from the kiln the ochreous mixture remaining on the surface is cleaned off, leaving the iridescent decoration. If an undecorated surface is desired, the mixture is painted or sprayed over the shape in a flat even coat. An irregular application, or a splashed or mottled coat of varied ochreous mixtures will produce an irregular surface.

The commercial metallic lusters on the market are applied over the glaze, as in china painting. They can, however, be used in connection with tin enamel decorations, the underglaze processes, and other decorative types. There are many possible methods and manipulations in luster work. The Persians, for instance, would decorate a bowl in underglaze colors finished in one or more colored glazes, adding the luster after the piece was fired. This treatment, of course involved a special firing for the luster. Often no luster was applied, the reducing atmosphere being responsible for the iridescence. In some examples the iridescence was not apparent when the pieces first came from the kilns, and only appeared after many years' exposure to the elements. In others the luster was caused by the action of the earths in contact with wares which have been buried for a considerable period. There are many fine examples of Italian majolica which have been finished in luster. Maestro Giorgio of Gubbio was famous for his luster decorations and often finished the majolica works of other decorators after the tin enamel decorations had been fired. Both the Persian and Italian overglaze lusters were the turpentine-metallic solutions which developed in an oxidizing atmosphere, and which are very similar to the lusters used in the china painting processes of today.

8. Overglaze Processes

The various overglaze processes are too well known to need much comment here. It is perhaps enough to state that it was inevitable that the potter would discover palettes of color and methods of decoration which would permit a wide range of hue and which would not be subject to extreme mechanical and chemical changes in the kiln.

All overglaze work, as the term implies is done over the glaze after the piece has been fired. The decorated ware is fired at a lower temperature than that involved in the production of the shape, or just enough to fuse the colors into the glaze. A wide range of colors has been developed in addition to gold, silver and the various lusters. The original overglaze work was no doubt the result of the potter's recognition of the limitation of the underglaze and the other processes together with his tendency to develop more highly finished decorative effects.

The Chinese decorator finding that he could not produce certain complementary colors by the underglaze process naturally resorted to the overglaze method, applying the reds, pinks and gold after the underglaze decoration was completed and fired. The Italians did the same thing with their lusters, as previously noted.

The overglaze process in its highest development is typically European. The French, German and English decorators have executed works which are marvels of technique. Pastes have been developed in order to do relief work in gold and the other precious metals. Jewels have been applied and fired to the surface of the ware, and etching has been done by means of acid resisting grounds and hydrofluoric acid. Overglaze printed decorations have been in common commercial use, and to a small extent even photographic processes have been used in connection with overglaze decorations.

Today the great bulk of commercial utilitarian ware is decorated by the lithographic process, and there is little doubt that this will be the standard commercial process for many years to come, although it is to be hoped that the copper plate printing process will be revived because there are many decorative effects which have not yet been developed, and which cannot be produced by any other process. In recent years the overglaze process has deservedly sunk into disrepute, although there will always be more or less good work done because this medium is an essential to certain types of ware.

9. Ceramic Sculpture

The most superficial survey of the existing works which may properly be classed as ceramic sculpture must impress the reader with the artistic possibilities of this branch of ceramic art. It is only necessary to refer to the terra cottas of the Aztec, Egyptian and Grecian periods of the Tanagra

figures, the delightful and beautifully modeled figures of the Han and T'ang dynasties, and later, the exquisite porcelain figures of the Ming and K'ang Hsi periods. The Japanese have also been responsible for some



FIG. 12.—Majolica panel executed by American Encaustic Tiling Company.

finely modeled works both in earthenware and porcelain. The European potters have almost always been interested in ceramic sculpture. The

Adams, Wheildon, Wedgwood, Spode and a number of later potteries have produced examples adequately demonstrating possibilities. The figures of Sèvres, Berlin, Dresden, Copenhagen, and the early Staffordshire figures are well known to the collector and connoisseur.

The sculptor has always been interested in the possibilities of faience and porcelain, but he has not been successful in obtaining the active co-operation of the potter.

Ceramic material possesses at least equal opportunities for the sculptor as marble, bronze and ivory. He is aware of this, and it only remains for the faience, earthenware and porcelain manufacturer to realize the commercial possibilities (for indeed there is an immediate and remunerative market for such work) and to coöperate with the sculptor in bringing about conditions where sculpture can be successfully executed.

There are three general methods by which ceramic sculpture can be made: (1) by firing the original model, (2) by casting, (3) by pressing.

If the subject is to be executed in terra cotta, faience or stoneware, and only one piece is needed, the original clay model may be fired providing a satisfactory clay is used and assuming that provision is made to remove the armature, and to otherwise adjust conditions so the subject may be fired without the risk of cracking or becoming distorted in the kiln.

The piece may be solid or hollow. If it is solid, the sculptor must use a sandy open clay subject to slight contraction, and he must be sure that the clay core is tightly put together and altogether free from air spaces.

Many of the Han and T'ang horses and other figures were the original models. The armatures of some of these pieces were of wood with straw or fibrous cores which burnt out during the fire. Openings were made at the base or in inconspicuous places to permit combustion and the escape of gases. The writer once repaired about twenty fine Han figures which had been badly smashed during shipment from China. All of these had been modeled around wooden and fibrous armatures which in a number of pieces had not been completely consumed.

The more delicate and intricate subjects, especially those made in porcelain are cast.

Large terra cotta, faience or stoneware figures are pressed. The most important essential next to that of appropriate technique in modeling is the correct type of mold. It is obvious that the sculptor in modeling for the ceramic process will consider the nature of the material. But however simple his subject, there will always be difficulties in mold-making and in getting a satisfactory reproduction in clay from the mold. Undercuts must be provided for either by means of slides, or by filling up those places which will not draw, and afterwards cutting away these additions. The latter work should always be done by the sculptor himself because there are always effects which cannot be obtained by means of the mold.

There are certain types of modeling which cannot at all be reproduced by means of the plaster mold, and the only solution for such works is the use of the gelatin mold which can be pulled away from the reproduction without

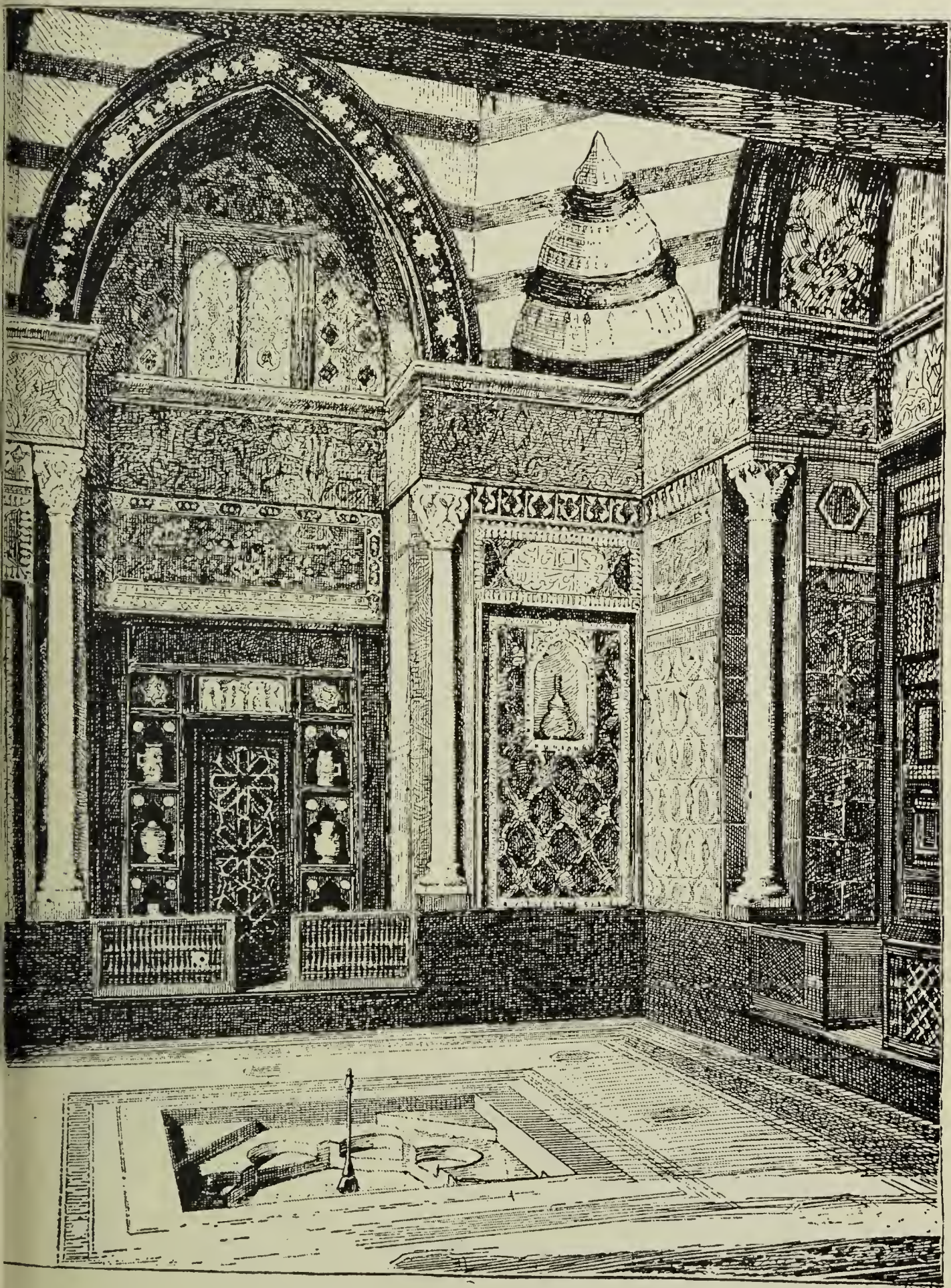


FIG. 13.—Arabian court in the house of the late Sir Frederick Leighton, London.

injuring it or tearing away overlapping details. This type of mold is used by the Italian plaster workers and it has been used by Conrad Dressler in

connection with his beautiful ceramic reliefs. But whatever method is used the condition must be one where the potter is working with the sculptor. It is impossible to do satisfactory work, for instance, under conditions where a subject is modeled five hundred miles away from the factory by a sculptor who has no knowledge of ceramic processes, and produced in a plant without his supervision or direction. It is a big undertaking to produce ceramic sculpture either in figurines or larger pieces. But there are many tangible signs that such work is going to be done in this country within the next ten years.

10. Architectural Pottery

Architectural pottery came into being at the time the primitive was aware of the plastic nature of clay and its hardening properties when subject to enough heat to expel the chemically combined water.

The period of national development depended on the state of the development of the particular country, and other conditions pertaining to available material and prevalent decorative interest. In those countries where stone and marble were readily procured, there developed a style of architecture suitable to these materials.

Sources of supply, local conditions and expediency were the general determining factors then as now.

Previous papers on this subject have appeared in this *Journal*, and we are about to publish a most valuable paper by Mr. Dressler on the possibilities of architectural faience, so it is not necessary for me to give an extensive historical outline. What I have to say at this time relates to present conditions in this country.

It would be grossly untrue and unfair to state, or imply that the terra cotta and faience manufacturers were not seriously attempting to develop the art to the point where we can rank with the best that has been done. Too much has already been accomplished in this country, and on a scale never before attempted, to question the fact that we are adequately preparing ourselves for the production of architectural work such as the world has never seen.

We may not have produced a porcelain pagoda, a Taj Mahal, a Della Robbia relief, or even a Petit Palace, but technically or practically speaking, we are (and have been during the past twenty years) producing architectural wares on a scale, and in a space of time which would have astounded the potters who were responsible for these earlier works held up for our example.

Present commercial conditions will not permit our spending from twenty to thirty years in the erection of a single building. A forty story structure must be completed in a few months, within a year at most, and naturally the result is in accordance with present requirements. The Spanish galleon

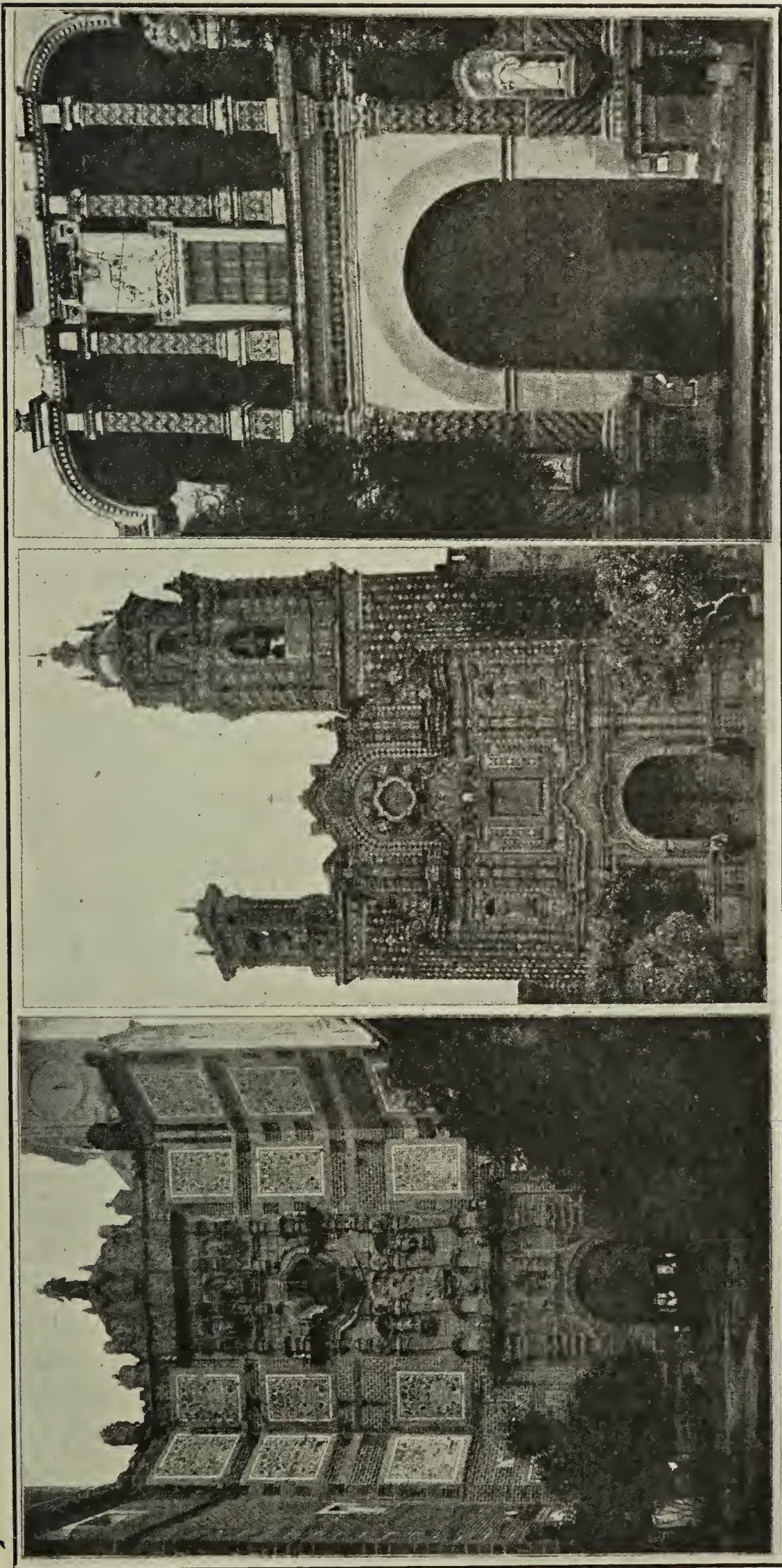


FIG. 14.—Mexican churches showing majolica tile and faience treatments.

may be more picturesque than the present day ocean liner, but it would be a poor substitute; and there is no question which ship the sensitive critic would select for an ocean trip. The old adage that beauty is only skin deep may certainly be applied to some of the old masterpieces. While I am unable, I think, to appreciate the visual glories of the Italian palaces, I know that I prefer to sleep in an American hotel and reside in a typical American home. Both these institutions are equipped and furnished with ceramic wares that could not be produced by the early potters. Our architects are concentrating on the fundamentals of service and comfort which were comparatively speaking, non-existent in the good old days. And in this we are only following the precedent adopted by our ancestors, the primitives, who only commenced to think of decoration and embellishment after the necessities (as they understood them) had been adequately provided for.

As stated, we are thinking seriously of the beauty of our surroundings and our architects and craftsmen are as much concerned as were the masters of the Renaissance and other periods. So far as the present achievements of our potters are concerned, it is only necessary to note that in terra cotta, tile and faience development, we are now leading the world. And we at this time have arrived at the stage where we realize that the artist and sculptor must be given a more important part to play in large scale production.

The only way to accomplish this is for the artist, sculptor and manufacturer to get together and come to a common understanding of the conditions involved.

The artist and sculptor must realize that the manufacture of terra cotta and tile is a business undertaking and not a millionaire's hobby. A capitalist will not invest in a proposition unless he can be reasonably assured of dividends. Neither will a clay manufacturer undertake to produce artistic terra cotta and faience unless it will earn a profit, and as a business undertaking, it must be subject to the same control as any other productive activity. It is not the slightest use for the ceramic artist to attempt to produce under the same conditions as were prevalent, for instance, during the erection of St. Marks, because modern industrial activities are vastly different. No important construction activity is undertaken without first estimating approximate cost and time involved, and without the creation of an organization which will efficiently direct and supervise the undertaking. This does not mean that the artist or sculptor is a machine, or that he must work under unfavorable conditions, but it does mean that aside from his skill as an artist he must possess an intelligent understanding of the industrial conditions of today. The philosophy holding that an artist or craftsman is a being entirely apart from the business man is as archaic as the science of medicine in the time of Gilgamesh. But the artist is one of the most important essentials, and however much

practical and technical skill may be employed and however elaborate the job may be, it is impossible to coördinate the various decorative developments without his assistance and direction.

If the artist can accept his obvious opportunities, and if the manufacturer can realize that he cannot manufacture artistic products unless he utilizes the services of competent artists, it will not be many years until American ceramic wares of every nature are shipped all over the world.

But the terra cotta manufacturer must remember that his wares are just as artistic as his artists are capable of producing. The judgment of a work of art is not a matter of opinion, although opinions may vary in regard to personal taste or choice of style, and to the initiated, *i. e.*, the architect, the critic and the tremendous purchasing power, who are influenced by the judgment of these two groups. The acceptance or rejection of what is good or bad in art is clearly defined, and it is a verdict that no amount of advertising or publicity from commercial interests can reverse. It is equally definite that while questionable artistic production may be marketable, it will never be acceptable at any price to those who know good art, while the highest prices will always be paid for the real thing.

The time is now coming when the manufacturer will realize that not every professional decorator or modeler is an artist, and that scores of these earnest and well-meaning gentry, at present engaged in the production of decorative wares, are as much out of place as a gentleman from Pell Street would be on Bailey's Beach.

This again is a question of selection and organization. What is needed is not so much a new productive element in the factory, but a new directing and supervising element.

THE ARTISTIC NEEDS OF MODERN FAIENCE

BY CONRAD DRESSLER

In this paper I shall expand the views which I ventured to put before you at the meeting of the AMERICAN CERAMIC SOCIETY at Columbus in 1921. The conclusions I then arrived at were that as regards pottery:

The achievements of the past owed their beauty to the artist.

The excellent technique of the present is due to the efforts of the manufacturer and scientist;

The latter quality has now almost entirely superseded the former;

Yet the esthetic needs are eternal and cannot be denied.

The efforts of solitary artists are unavailing in a modern world of vast undertakings.

It is for the modern factory to re-introduce the artistic spirit.

Whether everyone agreed with me I cannot tell, but no one in any case among the manufacturers and potters present expressed any contrary views. Possibly the statement was too general to invite criticism. I propose in this paper, therefore, to make some more definite and more concrete suggestions and to offer a plan for introducing artistic quality into modern terra cotta.

Let us first understand that when we speak of artistic work, we mean work done by an artist. A photograph of a picture may be very clever and very good, but it is only a copy of the work of an artist. It is the picture itself that we must call artistic. If this is true, then we are faced with the problem that faience work which is to be artistic must be done by artists and cannot be merely a reproduction of work done by artists.

But you will say that this is quite impossible in a modern factory. You cannot have a couple of thousand artists at work molding, pressing, enameling and coloring terra cotta. The cost would be too great, and, moreover, where could you get such an army of artists? Yet such armies of artists existed in the olden time, when the Alhambra was built, when the Mosques of Brussa and Damascus were erected, when Rhodian tiles were so freely used all over Asia Minor. But even if these artists could be brought to life again, you will say they would not fit in with modern needs.

The time now given for doing the work is curtailed. The conditions of life are altered. Instead of men, girls and women are now employed in many of the processes. These know nothing of the uses which their work serves nor do they care. They are concerned only about wages. They can be made to be more or less careful by discipline, but more than that cannot be expected of them. In fact, there are few men in a large establishment whose taste can be trusted.

As a rule, the work is imposed upon the manufacturer by the architect. He selects the colors, the texture, the glazes from a series of examples or



"Prudence"—Enameled faience panel, 6 ft. x 3 ft. 4 in., by Conrad Dressler,
Part of a decorative frieze in the Hall of the Law Society, London, England.

trials which are sent him, and as the shapes are all rigidly indicated in a blue print, the manufacturer's business, his whole duty and his only concern is to carry out the work as nearly as possible in accordance with the architect's instructions. If there is any artistry in the matter, it is entirely the architect's and if there is any credit for the job, it goes to him. He should share it in justice with the potter who made the trial pieces from which he selected the material he adopted. But even here, these trials may have been good and bad, and it was in the choice of the good or rather the suitable that the esthetic judgment had to be exercised.

But when all is said and done, and we look at the specimens of architectural terra cotta which adorn our large cities, it must be conceded that they are in no real sense artistic. They are not artistic in the sense of the buildings in Spain and in North Africa or Asia Minor which were done by the Arabs, and which were the first glazed or enameled terra cotta buildings to be put up in our era. Let us remember that this is an old art and that it had its origin in the Middle Ages. Our modern factories therefore have a pedigree and a very noble one, and we must see to it that we do not fall away from the high qualities of past achievement. Do not think that I propose that these old buildings should be copied. Let me tell you that such a thing is impossible, even if it were desirable. The modern architect can be trusted, moreover, as a man of culture and of taste not to fall into so grave an error as to attempt it.

But the architect, poor man, who wishes to do anything new and yet good, does not know which way to turn. He is not himself a potter, does not know the conditions under which pottery is best made, and on the other hand, he knows a great deal about stone work, so he designs a stone building and asks for pottery that shall look like stone. This is the principal reason for the failure of modern faience architecture. Stone is beautiful as stone, but pottery is poor stone, and yet pottery is magnificent, unsurpassable as pottery.

Look at the mosques in Turkey and tell me what stone building can compare with them. They gleam in the sun like jewels, their colors blend with the skies, with the dark cypresses, the green domes shimmer like jade and malachite. Can anything more fairy-like, more fantastically lovely be imagined?

I cannot believe that if the potters were able to place at the disposal of architects materials as enchanting as these, cultured as they are, they would not at once take them up enthusiastically.

Thus, the first part of my practical proposal is that you should not take your orders as potters from architects who can only give you drawings suitable for stone or granite buildings, but that you should show them specimens of such beautiful pottery-clad structures and so artistic that you will convert them to the use of pottery as a potter's material, and not as an

imitation of stone or granite. Now in order to achieve this, you need an artistic staff. Where will you get it or how will you train it?

Let me now explain what I consider as the first requisites, the natural and therefore the artistic requisites in architectural faience and terra cotta.

First, I do not think pottery should be constructional at all. It is not suitable for that purpose. It is true that bricks are constructional and are pottery, but when we come to tiling, to colored or plain enameled terra cotta, it is my strong belief that it should be treated merely as an outer decorative facing or skin to clothe the ribs of the building—what the French call *revêtement*. As a matter of fact that is what it is now, for your terra cotta blocks are hollow, for the simple reason that that is the only way you can make them, dry them and fire them, and when they are placed in a building, if they are filled with concrete it is for strength only.

Why not accept the limitation you are under of making pottery thin and get the architects to agree to design their buildings with a facing of enameled terra cotta and no strong projections as in the case of stone? The potters have such a splendid means of giving variety to a façade in the way of string courses, sky lines, jambs, pilasters, etc., denied to the stone buildings, for have they not color? Whereas stone must have projections in order to show the different members by means of light and shade. Let them make much of this color, it is their legitimate heritage.

Another thing that distinguishes pottery and makes it different from stone, is that it is worked soft and should retain this appearance of plasticity when it is fired. The surfaces should be rounded and undulating, and pleasantly full and rich. Stone, on the other hand, is expected to be hard and flat with keen arrises.

These qualities *belong* to the materials, and they should not be *taken out* of them. Yet that is what is universally done.

But we now come to a matter requiring something more than just leaving the material to be seen with its native qualities. The clay has to be shaped variously to suit the different parts of the building. How beautifully that was done in the past! Think of the Frieze of Lions, or of the Archers at Susa; of the many fine examples of Greek or Roman terra cotta. I have in mind a noble country mansion in England, Sutton Place, built in the days of Henry VIII by Italian potters. It is a Tudor building with mullioned windows and the walls are decorated with crests and emblems of great variety and beauty. The Della Robbias again carried the decoration very far in their figure work, in medallions and framed niches. All these are very delightful examples of what can be done. But who is to do this sort of thing in these days? It needs artists. Now, what exactly are artists?

We see beautiful laces preserved in the museums, and we appreciate their artistry. Who made them? Just common peasant women in

France or in Ireland. They were the artists. They varied their stitches, seeking new effects and often attaining great quality of design. These arts have nearly died out, because machinery has killed them, but I have seen these women at their work still, and I know how freely they worked.

Just the power to ornament is natural to men and women, and I am convinced that properly led, you could easily build it up among your employees.

I have had that experience in England. I employed children out of a village and gave them tiles to decorate in enamels. I had naturally to restrict their freedom. They could only work within certain limits, but the quality of their work was such that these tiles gained a foremost place among the artistic productions of their kind..

It is, however, necessary to make those to whom you would give a certain freedom of control over their production, thoroughly understand the purpose you have in view. Let us now see if it would be possible within a modern factory to organize an artistic production on the lines I have endeavored to indicate.

Shall we assume that a commonplace, a plain brick dwelling house, such as we have so many ugly examples of in some streets of New York or Pittsburgh, is to be faced with terra cotta. The opportunities which we have to beautify it are two-fold. There are the plain surfaces. There are the openings: doors and windows. The plain surfaces can be cut up by means of colored string courses, and the top of the building can have a rather wide decorative band, like a crown or crest. The jambs of the windows and doors on the other hand can be quite decorative with fruit and flowers, or other cheerful devices, and if we wish to be ambitious, we can put round arches above them and fill the tympana with some emblems. On the other hand, the plain surfaces must be interesting and beautiful also, but as a contrast to the decorative parts.

I should, for the plain surface, use tiles of an oblong shape and give them slightly concave surfaces so that they may have a quality of fulness and richness. Now such tiles could be run out of a pug mill in a stream wire cut in lengths, and just faced by hand in an iron frame. In this way the needed precision of size and shape would be obtained, but the hand facing would determine that character of plasticity which will be so valuable. The man or woman who does this work will become an expert at getting the right qualities as soon as he or she knows and can appreciate what is needed, what in fact looks nice, so that he or she should have this appreciation. I should provide, outside the factory in the open air, if possible in a pretty court yard planted with shrubs and flower beds, some blank walls upon which the finished work can be temporarily set for the purpose of enabling the work people to see what it is they have done, what it looks like when up, and whether or not it looks well.

This plain tile when fired will have to be enameled. Here again, to merely dip it into a plain enamel or to spray it will make it look mechanical. I would have the plain enamel dipping followed by the application with a coarse brush of a very liquid toned glaze. The hand work will cause a difference in the toning and will give a natural variety which will prevent even the plain part from being monotonous. It will look white, but still a little green, gray or rosy in places, just because it will be done by hand. Now the only artistry in this is the uncertainty of the human hand. But there is such a thing as negligence and as excess of contrast, and the girls who do this work will also appreciate this when they see their work up in the little court yard.

We now come to decorated parts. Let us take a string course, and let us suppose that we have decided to use a molding with a series of conventional roses at intervals and with some binding knot between. The field of design is so rich that it is endless, and I have named something very simple.

Let us suppose that these ornaments have to be fixed inside a *cavette* in the molding. The molding would, of course, be run through a mouth piece and cut in lengths. It would then be brought to the bench of the decorators. I assume that girls again, under the direction of an artist, would deal with it. Now these girls would be supplied with molds in which they would press the ornament and then fix it by means of slip to the face of the molding. They would have to be very careful to place the flower where it would belong and the knot ornament between and to press them down with their fingers. They would have a wooden tool in their hands with which they would make good any deficiency, and give spirit to the design, joining the two elements. There is nothing difficult about this, but it would exercise their artistic faculties, and when eventually they saw their work in position, they would be able to appreciate which was well done and which was not. Such work is nothing like so difficult as trimming a hat or making a blouse, and what young girl is not able to do that?

I will not go any further in the matter of slip decoration, because it is all along the same lines. The moldings can be more or less elaborate. The patterns can be as elaborate as you please, but by treating them this way, you bring freedom of human touch into play, and this is the artistic quality that tells.

Coming now to colors, let me say this. There is nothing more dangerous in such work than bad use of colors. If I were a potter, I should fix upon a particular tone for my plain surface, and I should make this so beautiful that I could do no better. Then I should stick to it and refuse to do anything else. And as regards the decorated borders, I should use four or five colors which suit my materials and which go well together, and then I should never vary them.

The variety would be in the motives. There you have the whole world before you. You have all the arts of Europe and Asia and nature itself to inspire you.

For the purpose of working out suitable decorative motives, you will need a few artists who will model them, and from their models the plaster mold can be taken, out of which the girls will squeeze them.

The latter can be taught also to model a little, so that they can do their work more intelligently and the more talented ones may in time become the modelers. With regard to central figure work for the tympana, or for panels, you may have to bring in an outside artist. But he must work in the factory with the others, and also see his work in the little court yard, otherwise he will not be able to judge of the effect; for a perfect harmony must exist between every part of the work, and therefore among the workers.

Does this sound like a dream? Certainly it has never yet been done here, but in a small way I have had that experience in my pottery in Birkenhead and later in Marlow, and I do not see why it should not be done in this country of progress and enlightenment. I venture to say that whoever undertakes it will be astonished at the eagerness with which the workers will take up the idea, and the spirit of good-will and enthusiasm which will animate them. The reason for this is that they will be treated once more like real people, not simply adjuncts to machines. Their sense of beauty will be awakened and cultivated, and as they give it out, the people who see the results will enjoy them as much as they themselves, for Art is a real bond between man and man, and we need that bond more in these days than ever before.

AMERICAN DRESSLER TUNNEL KILNS, INC.
CLEVELAND, OHIO

THE PROBLEM OF THE TURQUOISE ALKALINE GLAZE

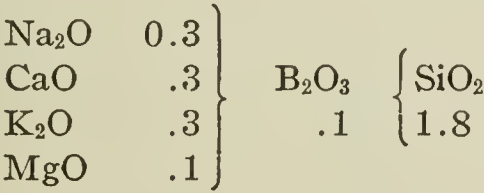
BY MYRTLE MERITT FRENCH

ABSTRACT

The method of producing a turquoise blue glaze which would be insoluble on the finished piece is described. This glaze is also designated to so cover the pottery as to make it impervious to water. The method requires a great deal of attention and it is doubtful if the result will ever be a great commercial success, but the beauty of the glaze makes it very satisfactory.

The object of this study was to produce a turquoise blue glaze which would be insoluble on the finished piece and would so cover the pottery as to make it impervious to water.

The experiments were fired in a muffle furnace to cones 09-06 for both clay and glaze. The following formula was used at first and the glaze was colored by copper oxide in amounts varying from 15 to 27 parts in the batch of glaze.



The ingredients were all fritted and ground for several hours. The result was a mass extremely difficult to manipulate, but the concern being at the moment chiefly with the color and fitting of the glaze, that difficulty was temporarily ignored.

The relation of glaze to body was approached by way of the clay. A first mixture was made consisting of:

Flint.....	53.8
J. P. No. 9 Ball Clay.....	16.0
Whiting.....	.2
	<hr/> 70.0

and upon this a triangular series was built in the following combination:

A. Clay.....	70
Glaze frit.....	30
B. Clay.....	70
Sharp sand.....	30
C. Clay.....	70
Whiting.....	30

Of this series number 9 seemed the best. The composition of this was:

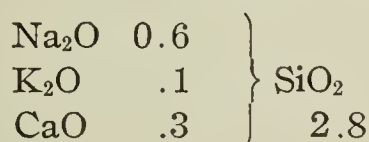
Flint.....	53.8
J. P. No. 9 Ball Clay.....	16.0
Whiting.....	12.0
Sharp sand.....	6.0
Frit.....	12.0

From these experiments, the following conclusions are drawn. Free flint must be from 60% to 64%. The addition of 4% to 8% of kryolith will lower the firing point of the body. The sum of the ball clay (J. P. No. 9), Georgia clay and feldspar may vary from 28% to 34%. One, two, or all of these may be used in the same body. If Cornwall stone is chosen, the body has more the appearance of a porcelain. A little whiting may be added if desired.

While evolving the clays as stated above, the glaze problem was not forgotten. The glaze given at the beginning was tested on every clay, but each time it crazed.

Every effort to use Al_2O_3 or B_2O_3 resulted in a greening of the glaze. Finally the R_2O_3 column was omitted entirely. PbO , BaO and MgO seemed to turn the glaze toward green. No perceptible difference was noticed in an interchange of K_2O and Na_2O . After numerous experiments it was found that 2.8 SiO_2 was the best content since a glaze containing that amount fitted practically every body made according to previous directions. A glaze with 3 SiO_2 crazed on the outside of a bowl when one having 2.9 SiO_2 did not craze on the inside of the same bowl. The two were handled simultaneously in exactly the same way except the glaze of the latter was thicker if anything. No attempt is made to explain this action.

Since PbO , BaO and MgO were to be discarded, only Na_2O , K_2O and CaO were left. CaO .3 was as high as the desired firing point allowed, leaving .7 for the other two. A glaze of this formula was therefore chosen:



of which the batch works out as:

Soda ash.....	64
Niter.....	20
Whiting.....	30
Flint.....	168

Na_2O .7 and CaO .3 was just as satisfactory. As it was not possible to frit all the flint, 100 grams of flint were included in the frit and 68 grams added raw. The raw flint ground in the ball mill with the frit kept it from sticking to the pebbles in a stone-like mass as did the glaze given early in this article. The resulting mass was difficult to manage unless mucilage was added; but by so doing, a skilled person could manipulate it with little trouble. It could even be sprayed. The glaze seemed entirely insoluble after being fired and was sufficiently viscous to stay in place—a statement which could not be made concerning the first glaze. Attempts were made to fit a glaze, engobe, and body clay, but that seemed too complicated a problem until a few further facts were established as a working basis.

From results obtained, however, there seems to be no doubt that the color effect can be obtained by that process.

It is very doubtful whether this type of pottery will ever be a success commercially, because each piece must be given much attention. However, the joy of the color in the finished piece is full recompense for the necessary care. Not long ago, it was asked if the fact had been noted that the color produced by copper in an alkaline glaze was so much more beautiful than color in any other glaze. It is the glory of the achievement in this very color that had made possible the enthusiasm and perseverance required to overcome the many difficulties and to devote the necessary time to the problem.

ART INSTITUTE
CHICAGO, ILLINOIS

THE POLARIZING MICROSCOPE AS AN AID IN FELDSPAR STANDARDIZATION

BY HOWARD C. ARNOLD

A colloquium was recently held on methods for the standardization of feldspar. Examination with the petrographic microscope was not, however, included among the suggestions offered, and it appears to the writer that the ceramic industry is losing valuable information by failing to utilize an instrument which can be of the greatest assistance in the evaluation of feldspar.

The practical applications of the petrographic microscope were pointed out by Dr. W. J. McCaughey in a paper before this SOCIETY in 1913.¹ Although the theory involved in the use of the petrographic microscope is not familiar to the average technical student, still the actual tests and methods of differentiation are of the greatest simplicity and can be mastered by any one who knows the elementary laws of light.

For the identification of crystalline minerals nine different determinations may be used; namely,

- | | |
|--|---|
| 1. Indices of refraction, or refringencee. | 5. Elongation (including sign, direction and extinction angle). |
| 2. Classification as isotropic, uniaxial or biaxial. | 6. Color. |
| 3. Birefringence. | 7. Pleoehroism. |
| 4. Sign. | 8. Dispersion. |
| | 9. Twinning habits. |

Any given mineral, depending upon its crystallization form may have one or all of the above characteristics. For a brief, concise statement of the principles underlying the determination of these properties the reader is referred to articles by Dr. W. J. McCaughey.² The sole purpose of this paper is to emphasize the importance of using the petrographic microscope in studying feldspars and all primary silicate minerals, or silicates separated from cooling magma.

A perusal of the papers and discussions presented to the colloquium shows important problems arising from the following factors:

1. Aecessory minerals occurring with feldspars which are detrimental to its use in eeramie work. The more important of these are
 - (a) Mieas (museovite and biotite)
 - (b) Garnets
 - (c) Tourmaline
 - (d) Hornblende
2. Free siliea or quartz.
3. Shapes and sizes of the grains produced by different methods of grinding.
4. Nature of dark impurities other than minerals mentioned above occurring in powdered feldspar.
5. Variations in quality in different shipments of feldspar.

¹ *Trans. Amer. Ceram. Soc.*, 15, 381 (1913).

² *Ibid.*, 15, 322 and 381 (1913).

In many cases the producers and consumers are handicapped by a lack of information on the above subjects, which makes it difficult for them to know in what direction to proceed for correction. The petrographic microscope can be considered an instrument placed at their disposal to assist in securing this information.

In order to illustrate specific applications of the microscope let us take up the above problems.

1. Accessory Minerals in Feldspar.—The two micas, muscovite and biotite, and sometimes the alteration product sericite, are easily identified in any mixture of finely ground minerals. By observing several slides, and actually counting the number of grains present one can tell the percentage of mica grains, either muscovite or biotite, or both, in any given sample of feldspar. This is of particular value to the consumer who receives his feldspar fully ground and cannot tell with the naked eye how large a percentage is present. The grains are distinguished from feldspar grains by (1) indices of refraction, (2) birefringence, (3) cleavage, (4) elongation, (5) color, and (6) in some cases pleochroism. Biotite is differentiated from muscovite by color, optic angle, and pleochroism. When biotite is altered its products are usually iron stained, whereas muscovite leaves colorless minerals.

By taking a small sample of a new feldspar and observing it under the microscope, a consumer can tell, even before purchasing, the amount and nature of the mica in the feldspar and whether or not it is going to give him trouble.

What has been said above for micas applies also to garnet, tourmaline and hornblende. Garnets are distinguished by being in the isotropic division, by their color, and by their index of refraction. The fact that garnets crystallize in the isometric system, and are, therefore, isotropic, distinguishes them immediately from all other minerals commonly found associated with the feldspars. Color and indices of refraction can be used to determine the kind of garnet. As with the micas so also with garnets, the iron-bearing variety being the one which causes the most trouble in the finished product.

Tourmaline is identified easily under the microscope. The one property of pleochroism alone is sufficient to identify it. This test is further supplemented by color, refraction and birefringence tests (although these latter are dependent somewhat on the composition) and also by its elongated crystal form. In any ground mixture of feldspar the amount of tourmaline present can thus be easily determined.

Hornblende is a dark, iron-bearing mineral; the percentage of iron varies. With increase in iron there is a corresponding darkening in color. The index of refraction, or refraction and birefringence are characteristic

of the mineral, as also the angle of cleavage, extinction angle, pleochroism and color. These properties make it a mineral easy to identify.

2. The Determination of Free Silica, or Quartz.—This problem has never been satisfactorily solved by chemical methods. The accepted chemical procedure as outlined by Mr. Ladoo¹ at its best offers a most unsatisfactory solution. With the petrographic microscope it becomes simply a matter of sorting out the actual quartz particles from the feldspar, an operation as simple as sorting peaches from pears. By using the proper oil, with an index of refraction between that of quartz and feldspar, and by setting the microscope to observe the Becke line reaction one merely counts the quartz particles in a total field. By observing several fields (and they will not vary to any great extent) the content of free quartz can be determined. This is a very important factor to consider in purchasing feldspar; and it can be determined in a satisfactory manner only by the use of a petrographic microscope.

3. Study of Grain Shapes and Sizes as They Are Produced from Different Grinding Methods.—Mr. Landers² has stated in his paper that different methods of grinding influence somewhat the shape of the feldspar grains produced, and in turn this difference in shape is the cause of differences in rate of settling. Of course the application of the microscope to this specific problem is obvious. However, it goes further and opens up a complete line of research upon the effect of different grinding methods upon the shape and size of particles; their influence upon the proportion of coarse and fine materials; the progress of the grinding operation with time and the effect of introducing variations in the process. Mr. Landers states that wet-ground feldspar will settle five times as fast as dry-ground, and yet both give the same screen analysis. What could be more natural than to actually examine these grains with the microscope with a view to finding an explanation for such an anomalous behavior? In determining fineness of grain a cross-sectional eyepiece could be used on which actual dimensions are read. Or if one wished to study carefully the proportions of different grain sizes, the whole field could be plotted for a permanent record.

4. Nature of Black Specks in Ground Feldspar.—Besides the dark colored minerals, which can be determined as outlined above, other black specks in feldspar can be identified. Free iron, accumulated through the grinding, elevating, and conveying machinery, as well as coal, cinders and dust, which may accumulate can be absolutely identified. With such information available one can find definitely the source of the black specks

¹ R. B. Ladoo, "Conditions in the Feldspar Industry," *Bull. Amer. Ceram. Soc.*, **1**, 7 [Feb. 20], (1922); "Colloquium on Feldspar," *ibid.*, **1** [7] 78-101 (1922); *ibid.*, **1** [8] 133-46 (1922); *ibid.*, **1**, 269-95 (1922).

² "Colloquium on Feldspar," *loc. cit.*, **1** [11] 271 (1922).

and take all possible steps toward their elimination. Needless to say, such information is invaluable.

5. Constancy of Quality in Shipments.—C. N. Franzheim¹ has drawn attention to the difficulty of getting uniform shipments of feldspar from year to year. However, the writer is inclined to agree with Mr. Lander in his reply to Mr. Franzheim when he says that none of the rock products entering into the ceramic industry occur in such a pure state and in such large bodies that they have to be considered only from the point of view of their preparation. In other words feldspar is not a prepared product, and as such its purity will of necessity be limited to the available deposit. If it were a soluble product, and could be dissolved, separated from its impurities, and precipitated, then a commercially pure product could be obtained. But where the nature of the material prevents such a process we shall have to resort to physical means, and of course in these we are distinctly limited. Gravity separations will undoubtedly assist in securing a purer feldspar but this method is limited because the impurities present do not vary enough from feldspar to make the method of general application. Any deposit of feldspar is more or less a mixture of minerals. Some are purer than others, but all contain some other minerals. Even our best potash-feldspars turn out to be microcline instead of orthoclase. Although these two minerals when pure have the same composition, still they have physical properties somewhat different, and after weathering their compositions will not be the same. Additional information is thus obtained on the character of the original feldspar deposit by knowing whether the actual mineral is orthoclase or microcline.

Besides being associated with each other the two potash feldspars are intimately mixed with soda feldspar. In fact the minerals orthoclase, microcline, and albite crystallize in an actual intergrowth called perthite. This intergrowth may or may not be visible to the naked eye. From albite to anorthite, the lime feldspar, we have a complete isomorphous series, albite, oligoclase, andesine, labradorite and anorthite being the principal members. These feldspars all have individual physical properties, and of course have a definite effect on the action of the bulk of feldspar. No wonder Mr. Franzheim points out the difficulty of getting his various shipments of feldspar to act uniformly. If he had an intimate knowledge of the exact ingredients which made up his feldspar shipment he could anticipate its action before he used it. If necessary he could modify the remaining ingredients in his body and correct for the feldspar impurities. If his second shipment ran higher in quartz than the first, he could decrease flint and increase feldspar accordingly. If his easily fusible soda feldspar content increased at the expense of the potash feldspar, he could decrease his total feldspar addition and increase refractories. The same reasoning

¹ "Colloquium on Feldspar," *loc. cit.*, 1 [11] 292 (1922).

plies to the presence of feldspars other than potash or of soda-feldspar the raw product. There would be required, of course, a large amount of empirical information before the method reached an application as specific as that outlined above, but the polarizing microscope is the tool by which this information can be secured.

The writer makes no claim to originality in the above discussion. He has made free use of the standard authorities on mineralogy and petrography. His idea is to point out the value of the petrographic microscope, the practical results which can be obtained by its use, and if possible, to emphasize the loss the industry is suffering by not adopting it for working out definite specifications for feldspars.

ARTHUR D. LITTLE, INC.
CAMBRIDGE, MASSACHUSETTS
November 21, 1922

FELDSPAR FOR GLASSMAKERS

BY F. C. FLINT

Introduction

Feldspar for a long time has been used extensively only by manufacturers of clay wares, such as porcelain, sanitary ware and enamels. Recently its use has grown into the glass industry to such an extent that it is developing into a considerable factor in the feldspar quarryman's business. As the feldspar was formerly ground according to potters' standards entirely, it was not as good for glassmakers. This was chiefly on account of its fineness. The cost of production also was higher because of the length of time required for grinding. It is hoped that producers of feldspar will be able to grind a coarser grade of material for glassmakers, which should enable them to do it more economically and at the same time assist them in keeping away from the liability of introduced contamination, for the less the material is handled the less the danger of introduced iron.

Use of Feldspar

The feldspar is added to the glass for its alumina content. The potash and soda is valuable, but not essential as it can be added economically in other forms. The use of alumina is an old custom, accidentally first, but now comparatively common. It is not an easy thing to get in the batch without proper control, part of which evolves on the producer of the raw material. The chief difficulty is the variation in alumina content and in the important constituents. If a glass formula is made up it should be kept constant.

If the ingredients such as the alumina or alkali vary, it is a serious matter for these variations tend to produce cords in the glass, one of

the most difficult troubles to locate and correct. Changes in the source of any one material may also cause this as well as variation in the composition of material from some one source. When these variations occur, the trouble is sometimes blamed on the batch formula or mixing when a series of analyses would show the true cause of the difficulty. And every one is not in a position to make a complete analysis on every car of material that comes in.

Feldspar is not the only thing that is used for its alumina content, occasionally alumina oxide or hydrate is used; also cryolite, clay, kyanite, obsidian, granite, mica and lepidolite. Their value is comparative according to the content of the material and the form in which it is found.

Grinding

Ceramic ware usually demands a feldspar of great fineness, 100 mesh or greater. On the other hand, for the glassmaker there is a limit to the fineness which is desirable. When mixed with batch material any material which is over 80-mesh in fineness has a tendency to ball up which means that ultimately the effective size of the particles in the batch is very much coarser than a very coarse grind. It is preferable to have a size of approximately 40-mesh. From a practical standpoint if the feldspar were ground to all pass a 40-mesh sieve, there would be sufficient particles of greater fineness to give a good average grade, and yet the feldspar would run much more freely than if it were 80-mesh finer. This not only facilitates the mixing of the feldspar in the batch but it cuts down the dustiness and the subsequent loss in handling. They should permit feldspar grinders to use a much simpler installation than they now can use, or should permit them to get a greater tonnage from their present equipment. It would eliminate the long, slow grinding in the ball mill to obtain the small percentage through a very fine mesh. A simple installation would be the use of a manganese jaw crusher feeding a continuous chaser mill or ball mill, from which the feldspar would pass through a 40-mesh screen, the oversize being returned to the mill. It would be very poor policy to sieve out the extremely fine material for one use and save the coarse for the glassmakers, because any free silica that may be present is hard enough to resist grinding and would greatly increase the total silica content in the coarse material and correspondingly decrease the alumina and potash content. A magnetic pulley would greatly reduce the liability of introduction of tramp metallic iron from the mill.

Feldspar Specifications

Iron.—Feldspar, which was used by potters, was chiefly inspected for fineness of grind and for small specks of color due to iron or iron bearing

minerals. Sometimes the amount of iron in a feldspar was very low, but if it was in a form which gave these dark specks it was impossible to use it. On the other hand, iron which was uniformly combined with the feldspar, did very little damage until it was so very high that it produced a yellowish color, provided always, that it did not show up in the form of specks.

The glassmaker is not interested in the form in which the iron may occur, for in the glass batch this iron melts and diffuses throughout the mass, giving the characteristic greenish cast. A relatively low quantity of iron oxide is desirable in an average flint bottle glass, so that it may be successfully decolorized. This iron may be introduced in a number of forms. It may occur as some of the high iron bearing minerals, such as pyrite, limonite, ilmanite, magnetite, garnet, hornblende, mica, etc., or it may be introduced from the machinery of the mill, or in handling. A quarry which contains iron in any of the mineral forms must be well sorted to remove these minerals. There are various methods of doing this, but practically all of them depend upon the ultimate care and skill of the quarryman. It is a fortunate quarry indeed that does not have to select extremely carefully. From the glassmaker's standpoint, these minerals, particularly garnet, ilmanite, tourmaline and mica are only considered from the iron they introduce, not on account of specks.

The iron which is introduced in the mill varies with the various types of mills and the care with which it is kept up. Conveyors can introduce iron as well as the grinding machinery and even cars during transit can introduce an appreciable amount. A magnetic pulley should be used to remove the metallic iron which is introduced in the operation of sorting, grinding and moving.

A very important feature in the production of feldspar is reliable information as to the content of iron oxide.

It should be remembered that the analysis is given, not as metallic iron, but as iron oxide, for it is in this form that most of the iron occurs naturally in rocks. The analysis should be given for iron oxide alone, not iron and alumina, and should extend to 0.01%. If the analysis is made by a reliable chemist, or commercial laboratory, particularly one who is accustomed to analyzing silicates, there is little danger that the analysis will be far from correct. This is particularly true of commercial laboratories where duplicate analyses are run before the report is made.

Alumina.—The alumina content for which the feldspar is generally selected, should above all things, be constant. It need not necessarily be high if the price is adjusted accordingly, but it should not vary from one lot to another. Inasmuch as this is one of the more difficult things to analyze for, and is slow work, it is not often checked up.

Silica.—Silica may be considered only as a diluting material in the glass trade. It makes no difference if it is combined or free, it can be bought cheaper in the form of sand and often more pure. It has no deleterious effect on the glass other than that a variable increase, particularly if it is not expected, changes the properties of the glass.

Alkalies.—The most important consideration in the use of feldspar is that the total alkali be constant and be high enough to warrant its use. If it is low it cuts down the value of the feldspar, for soda ash must be added, and if it varies it causes the glass to become harder or softer and in the case may be, another cause for cords, seed, etc.

Other impurities, such as lime, magnesium, titanium, etc., generally occur in too small quantities to be worth consideration. If they are present to any appreciable extent, it should be known so that the batch may be corrected to suit. Here too, unwarranted variation is harmful.

The greatest difficulty in obtaining a true analysis of such material is in the sampling. Oftentimes the analyst does not have the opportunity to do this and the man at the quarry does not have an adequate conception of the importance of this job. In most any quarry one can pick up perfectly pure, clean samples and he can also find rock which a quarryman would use. Nature does not produce chemically pure materials very frequently. Therefore, it is of very little use from a commercial standpoint, to select samples for analysis. A true representative of the quality of feldspar from any quarry can only be obtained by taking a frequent number of small samples during any given operation. If these are taken after the first crushing, and it is best not to take them before, a large pile of samples should be collected on a clean floor, turned over and over with the large lumps broken, and the pile reduced by quartering. Then, when the sample is made fairly small, the material should be ground in a separate, clean hand mill and further mixed and quartered until a small sample of sufficient size can be taken to the laboratory. In a quarry that is operating, the feldspar which is going out to the customer is most pertinent, so samples should be taken at regular and frequent intervals while the car is being loaded. This should then be thoroughly mixed and quartered down until a half pint sample is obtained and this should be sent to the analyst, who will then further quarter and sample until he gets a representative small amount from the sample which has been sent him. Only by going to this great care can reliable analyses be made. The customary habit of reaching in a corner of a door and filling a bag or bottle from some one spot on the surface has caused more unreliable analyses than any one practice of sampling.

THE MEANING AND MICROSCOPIC MEASUREMENT OF AVERAGE PARTICLE SIZE¹

BY G. ST. J. PERROTT² AND S. P. KINNEY³

The influence of particle size on the properties of pigments, fillers, and ceramic materials is well recognized. The meaning of the term particle size or average particle size is less clearly recognized. This paper endeavors to present an analysis of the term and to set forth a method of calculating average particle size which gives a value capable of physical interpretation. The results of microscopic measurements of samples of pulverized coal together with calculations of the average particle size are then given.

The work outlined in this paper was done in connection with the Trent process for cleaning finely ground coal.⁴ In this work it appeared desirable to investigate the relation between ash removal and fineness of pulverization or in other words to show quantitatively to what degree of fineness it was necessary to grind different coals in order to secure optimum separation of mineral matter from combustible matter. It was necessary (1) to define the meaning of average particle size as applied to our purposes and (2) to develop a rapid method for determining this value.

Various methods of computing the average particle size of a finely divided material have been employed by other workers. These have been discussed at length by the ceramics investigators. These workers have employed elutriation methods to separate that part of the material passing 200- or 300-mesh screen into fractions containing a range of decreasing sizes. They have been interested in determining the "average diameters" and relative "surface factors" of different clays. The surface factor⁵ has been shown to be proportional to the reciprocal of the average particle diameter or in other words to $\sum \frac{y}{d}$, where y is the percentage weight of the elutriation fraction of average particle diameter, d .

If it were possible, it would be desirable in elutriation procedure to make sufficient number of fractions so that each contained particles of identical size. As it is impracticable to make so large a number of fractions and impossible in any event to get so clean a separation, each fraction contains a range of sizes. It is necessary to calculate the average particle size of this fraction before calculation of the average particle size of the total sample can be made.

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⁴ Perrott, G. St. J., and Kinney, S. P., "The Use of Oil in Cleaning Coal," *Chem. & Met. Eng.*, **25** [5], 182-8 (1921).

⁵ See Ross C. Purdy, Ill. Geological Survey, *Bull.* **9**, 150-154 (1908).

Elutriation was too tedious a procedure for our work and seemed to advance us but little, due to the fact that the average particle size of the separate fractions must be determined microscopically. A method of estimating average particle size by a microscopic count of the gross sample was accordingly developed. The amount of time save by elimination of the elutriation procedure is enormous.

The "Diameter" or "Size" of a Particle

The particles of a pulverulent material are neither spheres nor cubes. Frequently one dimension is considerably less than the other two. Ordinary microscopic measurement shows but two dimensions, although the third dimension or thickness may be measured if necessary. Determination of a single dimension, "diameter," or "label" by which we shall designate a particle is difficult and an approximation at best.

If the particle is assumed to be rectangular and its dimensions are designated by l , b , and t , the average dimension of the particle might be calculated in one of several ways:

$$\begin{array}{llll}
 (1) \quad \frac{l+b}{2} & (2) \quad \frac{l+b+t}{3} & (3) \quad \sqrt{l \times b} & (4) \quad \sqrt{\frac{2lb + 2bt + 2lt}{6}} \\
 & (5) \quad \frac{3lbt}{lb + lt + bt} & (6) \quad \sqrt[3]{l \times b \times t} &
 \end{array}$$

(1) and (2) are statistical averages, (3) is the side of a square of area equal to the face examined, (4) is the side of a cube of surface equal to that of the particle, (6) is the side of a cube of volume equal to that of the particle.

Formula (5) is the harmonic mean of the dimensions and is related to the specific surface or surface per unit weight of the material.¹ The relation between the total surface S in unit weight of material of density ρ , consisting of spherical or cubical particles of diameter μ can be shown by arithmetic to be as follows:

$$\rho S \mu = 6 \quad \text{I}$$

Where the particles are rectangular parallelopipeds, μ can be shown to be the harmonic mean of the three dimensions.²

¹ Green, Henry, "A Photomicrographic Method for the Determination of Particle Size of Paint and Rubber Pigments," *Jour. Franklin Inst.*, **192**, 638 (1921).

$${}^2\mu = \frac{6}{S\rho}, \text{ where } S \text{ is surface per unit weight} \quad \text{I}$$

$$\begin{aligned}
 S &= N \times s, \text{ where } N \text{ is number of particles in unit weight and } s \text{ the surface of each particle} \\
 &= \frac{l}{\rho(lbt)} \times 2(lb + lt + bt)
 \end{aligned}$$

$$\text{Substituting in I, } \mu = \frac{3lbt}{lb + lt + bt} \quad (5)$$

(5) seems the most logical value to be used in work with pigments, ceramic materials, and fillers where a dimension related to the total surface per unit weight or volume is desired.

Since the labor of microscopic analysis cannot be increased indefinitely, it has been the custom, sufficiently accurate for most purposes, to measure the dimensions of the particles in one direction across the microscopic field giving in effect a summation of $\frac{l + b + t}{3}$ ¹. In our work, as described

later, the average dimension of the individual particles has been obtained by a visual carrying out of the operation indicated in (3). This value was employed because of the need for our purposes of a rapid method and not because we believed the value to be theoretically correct.

The Average Diameter or Average Particle Size

After we have obtained, with considerable effort, the relative numbers of particles of various diameters we are by no means at the end of our labors. We now desire a single value, an average particle size, which will express the degree of fineness of our material.

The value for this average particle which is at first sight most obvious is the statistical mean or $\frac{\sum nd}{\sum n}$ where n is the number of particles of diameter,

d . This procedure often gives undue weight to the smaller particles. A given sample may contain a small weight per cent of ultramicroscopic particles but such a large numerical percentage that the average diameter so calculated would be of ultramicroscopic magnitude. Statistically speaking the average particle is ultramicroscopic just as, numerically speaking, the average particle in a ton of run-of-mine coal is ultramicroscopic. Practically speaking, the value is often of little significance.

Workers with pigments and ceramic materials are interested in the tinting strength, covering power, or obscuring power of a pigment, and in the total surface exposed by the particles of a material to be used for ceramic purposes or as a filler. These properties are dependent not alone on the number of particles of a given size but on their surface. One 10-micron particle has a surface equal to that of 100 1-micron particles or of 10,000 0.1-micron particles.

The term *average* diameter or *average* particle size can be strictly applied only to the value calculated as indicated by the expression $\frac{\sum nd}{\sum n}$.

This value, however, merely indicates that size of particle which is present in greatest number. It is desirable to express the degree of fineness of a pulverulent material by some value which is directly related to its physical

¹ True for small particles whose dimensions are fairly symmetrical.

properties. For example, the particle size of a clay to be used as a filler should be expressed by a figure indicating the total surface in unit volume or weight, and the particle size of a finely ground coal should be expressed by a value indicating the extent of separation of impurities from valuable coal. As will be shown later, these values may differ considerably from the numerical mean diameter.

Green¹ in a recent article on determination of particle size of paint and rubber pigments, states as follows:

The character and behavior of fine pigments depends to a large extent on the magnitude of their specific surface. it is convenient to take for the diameter of a particle that dimension which bears to specific surface the simple relationship shown in equation (1) ($\rho S\mu=6$). If it is stated that the particle size of a sample of zinc oxide is 0.52μ , then it is meant that this is the diameter of the average particle. Such a fact may be used to determine specific surface but aside from this it gives but a poor visualization of the texture of the material, for it neither discloses whether the oxide is composed entirely of particles 0.52μ in diameter nor whether it is a mixture ranging from ultramicroscopic particles to grains as coarse as sand and average 0.52μ .

Green recognizes the importance of specific surface as a factor in determining the character and behavior of pigments but neglects it entirely in calculating his average particle sizes. He determines his averages on the basis of the number of particles of various sizes and takes no account of relative surface or weight represented by particles of various sizes. The error introduced in his averages is not large, due to the high uniformity of the pigments investigated. Consider, however, the pigment "ranging from ultramicroscopic particles to grains as coarse as sand." The specific surface of such a pigment would be considerably less than the specific surface indicated by the average diameter, 0.52μ , because the relative surfaces of the particles per unit weight of material have been neglected in calculation of this value.

The magnitude of the value for "average particle size" depends upon the weight given in calculation to the factors (1) number and (2) length, (3) surface and (4) volume of the particles of the several sizes. Thus the term "average particle size" is capable of various mathematical interpretations, many of which have little physical significance.

The influence of the method of calculation on the magnitude of the value for average particle size is apparent from the following calculations based on data from microscopic examination of a sample of pulverized coal.

Strictly speaking, equation (1), Table Ib is the only one of the four equations which gives an average diameter. The other equations give values which for certain purposes may be called *effective* average diameters. To avoid multiplication of adjectives, the term average diameter has been retained as referring to all four values but is in each case carefully defined.

¹ Henry Green, *ibid.*

TABLE Ia
MICROSCOPIC ANALYSIS OF PULVERIZED COAL

Diameter, microns	60	50	40	30	20	10	5	2
Relative number or frequency	87	100	156	660	1750	6200	25600	155000
Percentage of total								
1 Number: $\frac{n}{\Sigma n}$	0.05	0.05	0.1	0.3	0.9	3.3	13.5	81.8
2 Length: $\frac{nd}{\Sigma nd}$	0.9	0.9	1.1	3.5	6.1	10.9	22.4	54.3
3 Surface: $\frac{nd^2}{\Sigma nd^2}$	7.8	6.3	6.3	14.9	17.6	15.5	16.1	15.6
4 Volume: $\frac{nd^3}{\Sigma nd^3}$	22.5	14.9	11.9	21.3	16.7	7.4	3.8	1.5

TABLE Ib
CALCULATION OF AVERAGE PARTICLE SIZE

General Equation: $d_{av.} = \frac{\Sigma yd}{100}$ where y is the percentage of total (1) number, (2) length, (3) surface, (4) volume represented by particles of diameter, d.

Average particle size calculated according to percentage of total:

1. Number $d_{av.} = \frac{\Sigma yd}{100} = \sum \left(\frac{n}{\Sigma n} \cdot d \right) = \frac{\Sigma nd}{\Sigma n} = 3.0\mu$

2. Length $d_{av.} = \frac{\Sigma yd}{100} = \sum \left(\frac{nd}{\Sigma nd} \cdot d \right) = \frac{\Sigma nd^2}{\Sigma nd} = 7.0\mu$

3. Surface $d_{av.} = \frac{\Sigma yd}{100} = \sum \left(\frac{nd^2}{\Sigma nd^2} \cdot d \right) = \frac{\Sigma nd^3}{\Sigma nd^2} = 21.0\mu$

4. Volume $d_{av.} = \frac{\Sigma yd}{100} = \sum \left(\frac{nd^3}{\Sigma nd^3} \cdot d \right) = \frac{\Sigma nd^4}{\Sigma nd^3} = 36.4\mu$

With the aid of a table of squares, cubes, and fourth powers, the calculations involved are not prohibitively laborious.

Discussion

Table I and the curves in Figure 1 show the changes in the relative percentages of particles depending on the method of calculation. While 82% of the total number of particles are 2 microns in diameter, only 1.5% of the total volume or weight is represented by these particles. These differences are reflected in the different mean values.

Equation (1) is the numerical mean usually employed. It has no significance except as it means that the average diameter so calculated multiplied by the total number of particles in the sample will equal the summed diameters of the particles in the sample.

In equation (2) the term length is taken to mean the sum of the diameters of the particles of a given size.

Equation (3) gives a value for the average particle size which is to be interpreted as follows: A unit volume of material consisting of particles of this size only will have a total surface identical with that in a unit volume of the sample under investigation. Such a mean diameter seems a logical value to apply to paints, pigments and fillers since its use affords direct comparison of total surfaces in unit volume, or in unit weight (specific surface).¹ In comparing materials of different specific gravities it seems most logical to calculate average particle size as shown obtaining a value related to surface per unit volume. The specific surface or surface per unit weight may then be obtained by the relationship $d_{av.} = \frac{6}{S\rho}$.

Equation (4) gives a value of use in problems of ore or coal concentration. Here we assume that the amount of gangue remaining attached to the metallic ore or to the good coal is directly proportional to the diameter and to the weight of the particles, the *degree* of attachment being proportional to the diameter and the *quantity* to the weight. Thus the expression² Σyd where y is in weight per cent has been used in calculating mean diameters in connection with our work on the Trent Process of cleaning coal.

In each case, the average diameter is the mean value which would be obtained by integration of the curves shown in Figure 1. The occurrence of the fourth power of the diameter in equation (4) is difficult to interpret, but the value for mean diameter obtained by use of this equation has physical significance. In the example in Table Ib, the value 36.4 microns in equation (4) indicates that one-half of the weight of the sample consists of particles 36.4 microns or less in diameter and one-half consists of particles 36.4 microns or greater. In other words, if there is a proportionality be-

¹ Specific surface, $S = \frac{6}{d\rho}$ where d is the diameter of particle and ρ the specific gravity of the material.

Average diameter, $d_{av.} = \frac{6}{S\rho}$ where S is the total surface in 1 gram of the sample.

$\frac{6}{\Sigma(y_s)\rho}$ where y is weight per cent of particles of specific surface s

$$= \frac{6}{\rho} \left(\frac{1}{\frac{\Sigma(nd^3 \cdot s)}{\Sigma nd^3}} \right) = \frac{6}{\rho} \left(\frac{1}{\frac{\Sigma \left(nd^3 \times \frac{6}{d\rho} \right)}{\Sigma nd^3}} \right) = \frac{\Sigma nd^3}{\Sigma nd^2} \quad (3)$$

² y_1 = the weight per cent of particles of diameter $d_1 = \frac{n_1 d_1^3}{\Sigma nd^3}$

$$\Sigma yd = \Sigma \left(\frac{nd^3}{\Sigma nd^3} \cdot d \right) = \frac{\Sigma nd^4}{\Sigma nd^3}$$

tween the amount of mineral matter physically attached to pure coal and the fineness to which the coal is pulverized a sample of this coal in which the particles were all 36.4 microns in diameter would contain the same percentage of mineral matter attached to the pure coal as contained in the sample under investigation.

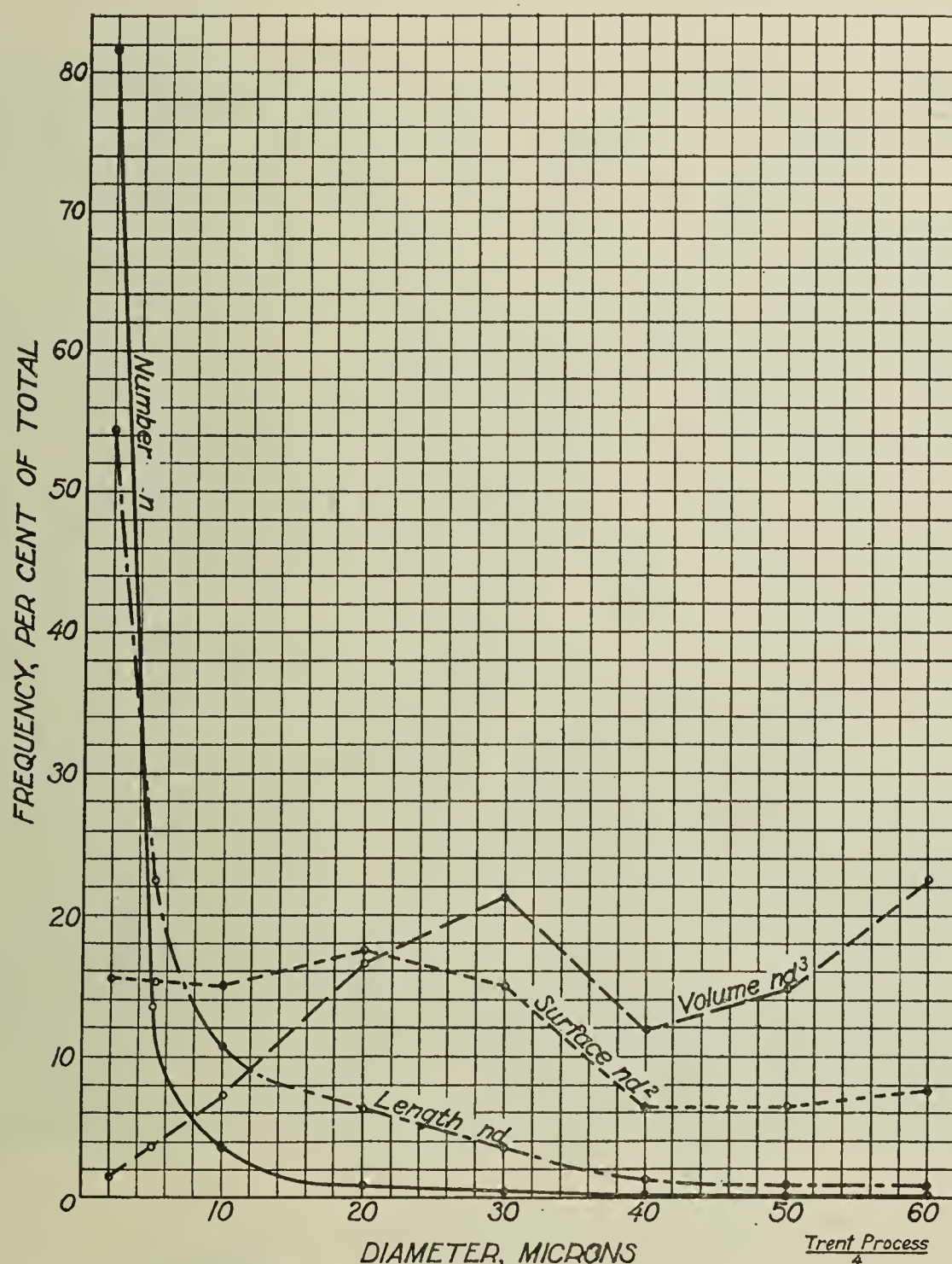


FIG. 1.—Graph showing distribution of particles in sample of pulverized coal according to percentage of total.

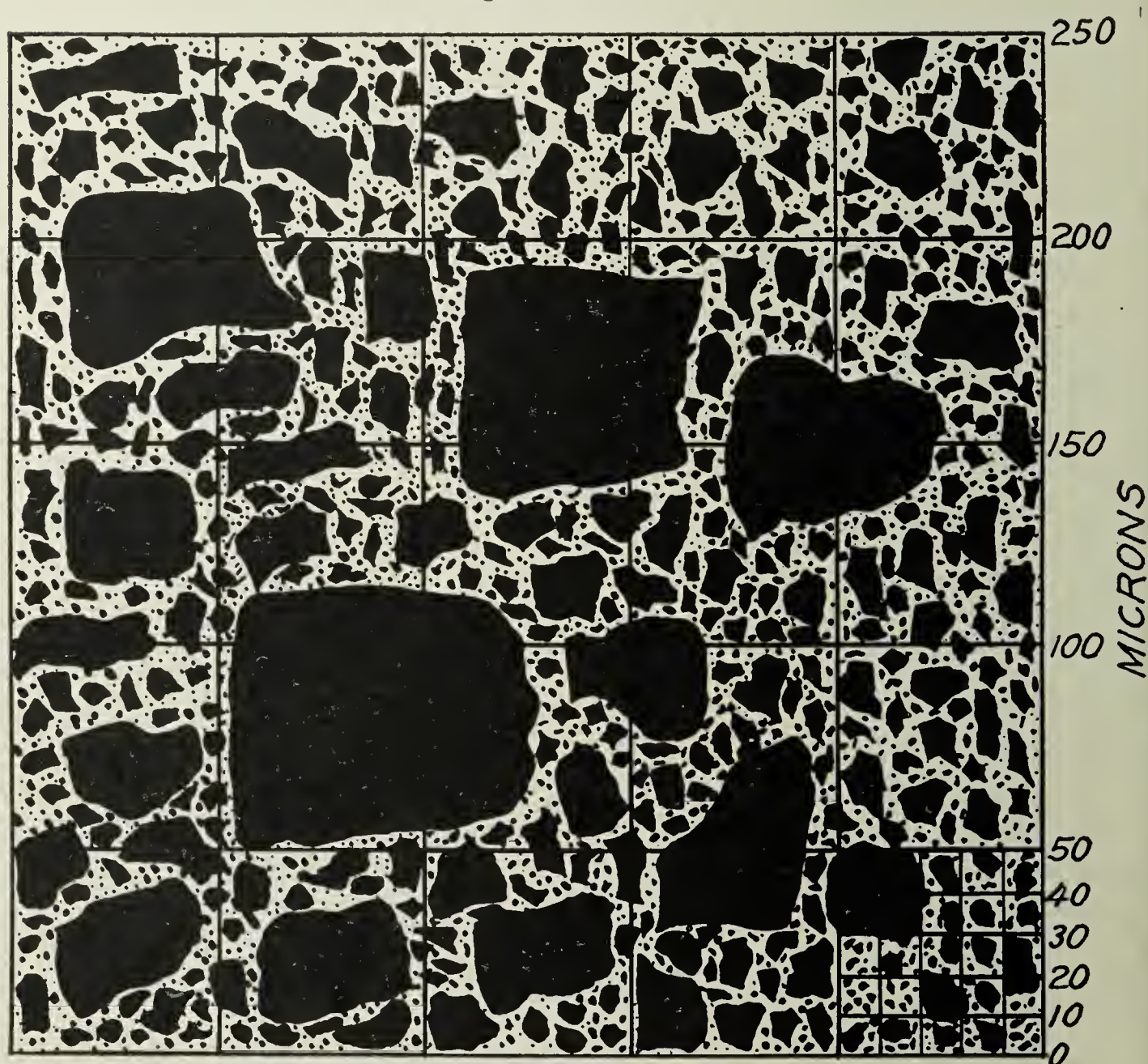
Mr. C. M. Bouton,¹ physical chemist of the Pittsburgh Experiment Station of the Bureau of Mines, has suggested the following explanation of the values obtained from equations (1), (2), and (3) in Table Ib.

If the particles are dropped on a surface so that they do not roll after striking and if they are then moved into a single line without any rotation during the moving, the

¹ Private communication.

length of the line would be nd and the average length of the particles in the line would be 3.0 microns. If now, without altering the vertical depth of any particle, the irregularities in the line are smoothed out so as to make it of uniform width throughout, with the additional condition that the total exposed surface remain unaltered, the width of the line

Coal ground to pass a 200-mesh screen.
Magnification, 500 diameters
diagrammatic.



Average particle size according to

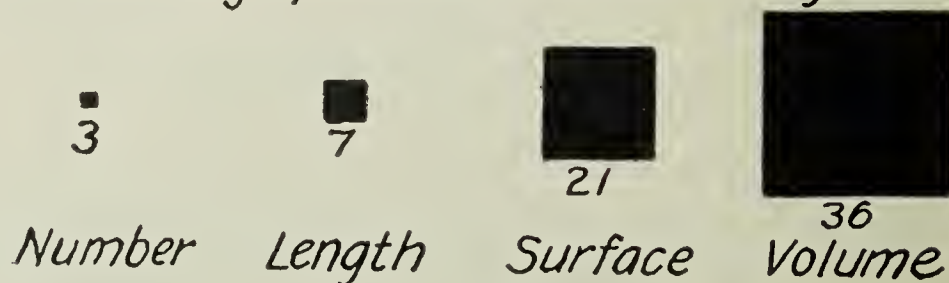


FIG. 2.

would be 7.0 microns. If the vertical inequalities were similarly smoothed out, the vertical depth necessary to give the true volume of the particles would be 21.0 microns.

Approaching the matter from this point of view, the average particle might be said to be one whose dimensions are $3 \times 7 \times 21$, or $l \times b \times t$, in which l is the average

length, $l \times b$ the average visible surface and $l \times b \times t$ the average volume. These three values considered together give an indication of the manner of distribution of the particles of various sizes.

The fact is, of course, that it is impossible to find a length, x , such that n equal cubes or spheres of diameter d will have the same total length, surface, and volume as any n fortuitous objects. The diameter d will inevitably be different according to the choice of length, surface, or volume as the valuable property of the objects. If but a single figure is given to represent the average particle it would therefore seem essential to specify whether the figure represents the average length, surface, or volume.

To the authors' knowledge, none of these methods of calculating average particle size have ever been applied to the results of a microscopic count, with the exception of the numerical method (1). The ceramists have calculated surface factors by multiplying the weights per cent of their elutriation fractions by the reciprocal of the diameter and have calculated average diameters by multiplying weights per cent of their elutriation fractions by the diameter itself, *i. e.*, surface factor = $\Sigma \frac{y}{d}$ and average

diameter Σyd where y is in weight per cent. Thus their average diameters and surface factors are not comparable. It would seem logical to calculate average diameter and surface factor on the same basis, *i. e.*, average diameter = reciprocal of surface factor.

It should be borne in mind that the term average diameter is of little practical value unless carefully defined. The "average diameter" or "average weight" of a given number of cannon balls and lead shot are meaningless except as mathematical values. Sufficient shot might be cut out of one cannon ball to make the numerical average diameter or average weight or volume close to that of the shot. To have physical significance the term must be carefully qualified.

Figure 2 shows a graphical representation of the coal samples in Table I, together with the size of the average particle calculated in various ways. The absurdity of the numerical mean diameter is immediately apparent.

"Mellor's Mean" and Other "Means"

Various workers have proposed methods of obtaining the average particle size by calculation from the magnitude of the largest and smallest particles present. "Mellor's mean" has been widely used by ceramists in calculating the average particle size of their elutriation fractions. To quote Mellor:¹

The arithmetical mean of the limits cannot be the correct representative average for the numbers of a group containing a large number of particles. To obtain the true representative value it is necessary to sum the diameters of the indefinitely large number

¹ J. W. Mellor, "Jackson's and Purdy's Surface Factors," *Trans. Eng. Ceram. Soc.*, 9, 94 (1910).

of particles in the given group and divide by the total number of particles in the group. This is impracticable by arithmetic. We therefore turn to the integral calculus which enables us to cope with the difficulty.

Mellor then gives the formula from the theorem of mean values:

$$\text{Mean } \frac{\int_b^a y dx}{a - b} \text{ where } y = f(x)$$

and proceeds to derive an expression for the average volume in a sample containing particles ranging from d_1 to d_2 in diameter.

$$\begin{aligned} \text{Average volume} &= \frac{\frac{\pi}{6} \int_{d_2}^{d_1} x^3 dx}{d_1 - d_2} \\ &= \frac{\pi}{24} \times \frac{d_1^4 - d_2^4}{d_1 - d_2} \end{aligned}$$

Average diameter d of sphere with average volume $\frac{1}{6} \pi d^3$ will be

$$\sqrt[3]{\frac{d_1^4 - d_2^4}{4(d_1 - d_2)}} \quad \text{or} \quad \sqrt[3]{\frac{(d_1 + d_2)(d_1^2 + d_2^2)}{4}}$$

Mellor assumes that his formula gives him the true arithmetical mean when the diameters range in an evenly graded¹ series between given limits. Actually, however, it gives him a diameter calculated from the mean volume. This will always be somewhat higher than a mean diameter calculated from a summation of the series of diameters divided by the number in the series, and it is a question whether such a mean has any significance other than a formula which gives slightly more weight to the larger particles. It is certainly not the true representative value as defined by Mellor in the quotation given above, which, contrary to Mellor's statement is simply the ordinary arithmetical mean.

Assuming with Mellor that the diameters range in an evenly graded series, it can also be shown by calculus that the mean diameter calculated from

$$(1) \text{ Number is } \frac{1}{2} \frac{d_1^2 - d_2^2}{d_1 - d_2} \text{ or } \frac{1}{2} (d_1 + d_2)$$

$$(2) \text{ Length is } \frac{2}{3} \frac{d_1^3 - d_2^3}{d_1^2 - d_2^2}$$

$$(3) \text{ Surface is } \frac{3}{4} \frac{d_1^4 - d_2^4}{d_1^3 - d_2^3}$$

$$(4) \text{ Volume is } \frac{4}{5} \frac{d_1^5 - d_2^5}{d_1^4 - d_2^4} \text{ or approximately } \sqrt[3]{\frac{d_1^3 + d_2^3}{2}}$$

¹ Meaning one particle of each size.

Thus the authors might add several more "means" to the already large number, did they believe any such expressions of value. Certain assumptions of continuity must always be made in deriving an expression for a mean value between limits. Our work with pulverized coal has failed to show any consistent distribution of sizes. Green¹ has found this to be true in his work with zinc oxide and has expressed the manner of distribution in a given sample by the precision or "uniformity" coefficient.

In a paper by Ashley and Emley,² data are given as to sizes of the elutriation residues of a Tennessee wad clay. The average diameters are calculated by various methods. The correct edge considered by these au-

thors is $\frac{\sum \sqrt{l \times b}}{n}$, *i. e.*, the numerical mean diameter. We have taken

from the curves their data on the number of particles of each size with sufficient accuracy for the purpose and have calculated the average particle size by (1) employing various "means" of the maximum and minimum diameters and (2) using the detailed data in Table II for calculation of the average diameter by the several methods previously described. Calculations from the data on the sample of pulverized coal have also been included.

TABLE II
DATA OF ASHLEY AND EMLEY² ON TENNESSEE CLAY
(Taken from Curves in their Fig. 4)

Can 2, diameter (microns)	No. particles	Can 1, diameter (microns)	No. particles
46.8	1	131	1
40	1	120	1
36	1	110	1
35	1	102	3
33	1	101	2
31	1	93	1
30	1	86	1
29	1	85	2
27	5	84	1
26	1	83	1
25	2	81	1
24	2	80	3
22	8	77	2
21	4	74	3
20	1	72	1
19	1	71	3
18	1	69	2
16	4	68	1

¹ *Loc. cit.*

² H. E. Ashley, and W. E. Emley, "Errors in Determination of Grain Size of Minerals," *J. Ind. & Eng. Chem.*, **3**, 87-91 (1911).

TABLE II (Continued)

Can 2, diameter (microns)	No. particles	Can 1, diameter (microns)	No. particles
15	1	67	3
14	2	65	1
12	3	63	1
10	3	61	3
6	3	59	2
..		57	3
..	..	56	3
..	..	54	1
..	..	53	1
..	..	45	2

Table III shows the wide range of values obtained by the different means and the difficulty of attempting to obtain a true mean diameter from any expression involving only the limiting sizes. If a “mean” must be used, the arithmetical mean is probably as good as any other.

The differences between the values for average particle size as calculated from number, length, surface, and volume are shown to decrease with decreasing disparity in the numerical quantity of various sized particles. Thus in the case of the sample of pulverized coal in which 82% of the total number of particles and but 1.5% of the total weight were 2μ in diameter, the average diameter according to number is 3.0μ, according to volume 36.4μ. In case of the clay elutriation fraction in can 1, the corresponding values are 74.8μ and 89.8μ, respectively.

Methods of Classifying Fine Particles as Used by Other Workers

Sieves cannot be used for sizing particles finer than 50μ. That portion of a sample which passes a 300-mesh screen must be sized by other means. Workers in ceramics, cement, flour, paint, and soils, have employed the following methods¹ (1) and (2), page 429.

TABLE III
CALCULATIONS OF AVERAGE PARTICLE SIZE

	Can 1 ¹	Can 1 ¹	Pulverized coal ²
Maximum edge	131	47	60
Minimum edge	45	6	2
Arithmetical mean $\frac{1}{2} (d_1 + d_2)$	88	26.5	31
Geometrical mean $\sqrt{d_1 \times d_2}$	76.8	16.8	11.0

¹ See the following: Wiley, Harvey W., “Principles and Practice of Agricultural Analysis,” pp. 200–226, Chemical Pub. Co., pp. 636 (1906). *Bull.* **38**, Bureau of Chemistry, Dept. of Agriculture, p. 60. *Bull. soc. Imp. des nat. Mos.*, [1], 324 (1867). Pearsor J. C., and Sligh, W. H., “An Air Analyzer for Determining the Fineness of Cement,” Bureau of Standards Technologic Paper No. 48, 1915, 74 pp. Schurecht, H. G., *Jour Amer. Ceram. Soc.*, **3**, 355–78 (1920).

Laschinger's mean	$\frac{d_1 - d_2}{\log_e d_1 - \log_e d_2}$	80.3	19.9	17.1
Mellor's mean	$\sqrt[3]{\frac{(d_1 + d_2)(d_1^2 + d_2^2)}{4}}$	94.5	31.0	38.2
Von Reytt's mean	$\frac{0.87}{2}(d_1 + d_2)$	76.6	23.1	27.0
Mean of form ^{3 4/5}	$\left(\frac{d_1^5 - d_2^5}{d_1^4 - d_2^4}\right)$	105.8	37.6	48
Average particle size from the detailed data according:				
to 1. Number	$\frac{\sum nd}{\sum n}$	74.8	21.0	3.0
2. Length	$\frac{\sum nd^2}{\sum nd}$	80.1	24.8	7.0
3. Surface	$\frac{\sum nd^3}{\sum nd^2}$	83.6	27.8	21.0
4. Volume	$\frac{\sum nd^4}{\sum nd^3}$	89.8	30.9	36.4

- (1) *Sedimentation*.—Descent of particles through a liquid at rest.
(2) *Elutriation*.—Moving column of fluid sufficient to neutralize rate of fall due to gravity for the size particle being carried over.

In our work, both sedimentation in water and elutriation with air and water have been employed. None of the methods have been found satisfactory for separation of fine particles, *i. e.*, 20–0 μ in diameter, nor have they been found particularly satisfactory for the separation of samples containing particles from 50–0 microns. Depending on the fineness of pulverization, elutriation of a 20-gram sample will take from 2 days to a week or more, and even then the fractions into which the sample is so divided always contain particles of considerable variation in diameter.

Inasmuch as a microscopic method of calculating the average size of each elutriation fraction was necessary, it occurred to us to endeavor to calculate the average size of the entire sample without resort to elutriation and compare the average size so obtained with the average size calculated from the results of elutriation of the same sample.

Microscopic Method of Classification Procedure.—In the microscopic method as finally developed, the sample is mounted in Canada balsam, diluted with about 20% xylol. A few drops of this mixture are placed on a piece of window glass and a small amount of the pulverized coal sample mixed with it until the particles are evenly disseminated in the balsam. Two slides 50 x 75 millimeters are used for mounting the sample. A

¹ Data of Ashley and Emley, *loc. cit.*

² Data of authors.

³ See p. 426.

the aid of the squared ruling of the eyepiece. Such procedure is approximate but probably gives values as nearly correct as any method can give in the irregularly shaped particles.

In making this count particles are grouped as being 1, 2, 5, 10, 15, 20, 30, 40, etc. microns in diameter. Our practice has been to count the number of largest particles first. Sufficient areas are examined so that a fair average of the number of particles of each size in a quarter field is obtained. For a sample of coal which has been passed through a 200-mesh screen, this will entail estimation of the number of particles 2 and 5 microns in diameter in about 10 areas, 10 and 15 microns in diameter in some 40 areas, 20 and 30 microns in diameter in some 100 areas, while as many as 300 separate areas may have to be examined for a correct estimation of the average number of particles 40 microns and over.

Calculation.—An example of the method of calculation is given below:

	Diameter in microns	Average number of particles in a quarter-field
	20	1
	15	3
	10	40
	5	110
	Rel. weight	Per cent by weight
1×20^3	8000	11.1
3×15^3	10125	14.1
40×10^3	40000	55.6
110×5^3	13750	19.2
Total relative wt.	71875	100.0
	Micron	
0.111×20	2.2	
$.141 \times 15$	2.1	
$.556 \times 10$	5.6	
$.192 \times 5$	1.0	
Aver. size	10.9	

In routine calculation it is more rapid to make the calculation as indicated by the expression $\frac{\sum nd^4}{\sum nd^3}$ which gives a value identical with that obtained above.

A sample data sheet showing an actual determination on a sample of anthracite culm, 200 mesh, follows:

TABLE IIIa							
SAMPLE DATA SHEET SHOWING METHOD OF ESTIMATING AVERAGE DIAMETER							
Number of Particles in a Quarter-field							
60u	50u	40u	30u	20u	10u	5u	2u
..	1	1	3	3	4	10	..
..	1	1	1	4	..	19	165
1	..	1	2	6	6	28	..

TABLE IIIa (Continued)

	60u	50u	40u	30u	20u	10u	5u	2u
..		1	1	2	1	2	9	140
1		1	1	3	2	4	20	..
..		1	1	2	4	9	12	150
1		1	1	2	4	5	16	..
1		1	1	2	4	3	43	140
1		1	..	2	3	6	36	150
1		1	1	2	6	8	28	140
1		1	1	2	4	6	44	..
1		..	1	2	3	6	40	..
1		1	1	2	5	5	18	160
1		1	1	..	5	12	56	..
1		1	1	1	5	4	33	165
1		1	1	2	2	8	13	..
1		1	1	2	1	7	26	..
1		1	1	3	2	4	14	..
1		..	1	2	6	6	26	160
1		1	1	2	1	5	30	..
..		..	..	2	4	13	..	..
1		1	1	4	3	10	19	190
..		1	..	2	6	7	32	..
1		1	1	2	4	8	..	150
1		..	1	4	3	8	..	..
..		1	1	1	4	10	30	..
..		..	2	1	3	4	..	..
1		1	1	..	5	8	19	..
..		1	1	2	3	5	..	..
..		1	..	2	2	4	26	..
(a) Total number of particles in fields counted.....	21	24	28	59	105	187	666	171
(b) Total fields counted	230	240	180	90	60	30	26	1
Average no. of particles per field ($\frac{a}{b}$) .....	.087	.100	.156	.66	1.75	6.2	25.6	15

Calculations

No. particles per field	Diameter microns	$d^4 \times \text{No.} \times 10^6$	$d^3 \times \text{No.} \times 10^6$	% Each size by weight
0.087	60	1.127	0.0187	22.4
.100	50	.625	.0125	15.0
.156	40	.400	.0100	12.0
.66	30	.531	.0177	21.2
1.75	20	.280	.0140	16.8
6.2	10	.062	.0062	7.4
25.6	5	.016	.0032	3.8
155	2	.022	.0012	1.4
		3.043	.0835	100.0
Average diameter = $\frac{3.043}{.0835} = 36.4$ microns				

Comparison with Results of Elutriation

It was now necessary to compare our results with those obtained by elutriation. A simple water sedimentation apparatus and an air elutriation apparatus were used. Figure 4 shows the air elutriation apparatus. This apparatus is modeled after that of Pearson¹ with certain modifications. The most important change in the apparatus of Pearson has been the addition of a flowmeter, thus doing away with the necessity for different orifices at different rates of flow and eliminating the errors due to changing back pressure as discussed by Pearson. The rubber sheet and tapper at the bottom of the coal reservoir serve to prevent packing of the finely powdered coal, a device designed by Pearson² after publication of his

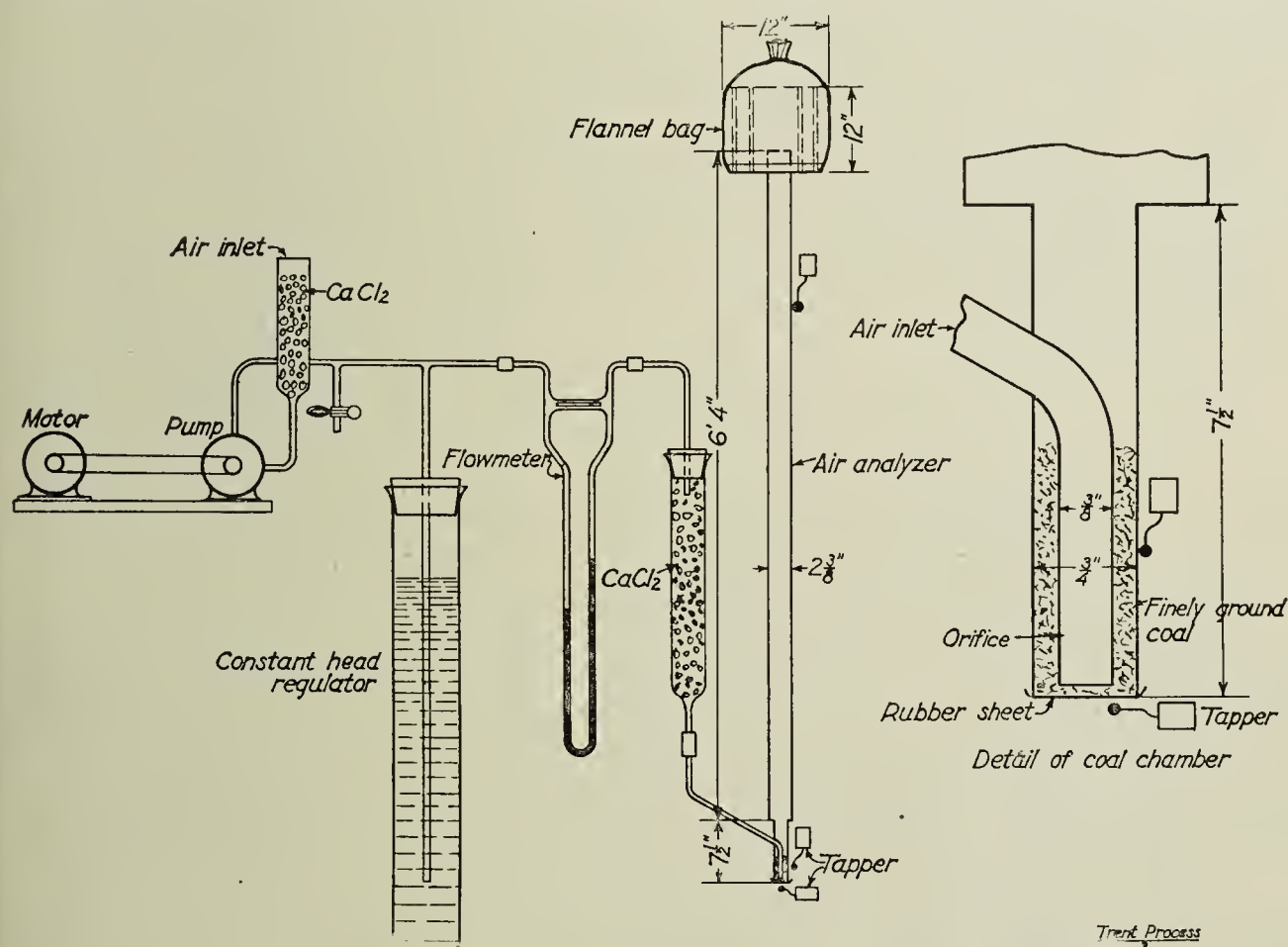


FIG. 4.—Air elutriation apparatus for finely ground coal.

paper. A Shulze water elutriation apparatus was not available, and a simple vertical tube elutriator was not found to give good results.

In Table IV a comparison is given of the results obtained by elutriation, sedimentation, and microscopic estimation of the original sample. All weights are given in percentages of the original sample. The calculated average diameter of the particles as calculated from air elutriation data was 32.0 microns, from water sedimentation data 32.5 microns, and from microscopic estimation of the original sample, 35 microns. This latter value agrees fairly well with the values from sedimentation and elutriation considering the difficulties of the experimental procedure.

¹ J. C. Pearson, and W. H. Sligh, *loc. cit.*

² J. C. Pearson, Private communication.

TABLE IV
COMPARISON BETWEEN RESULTS OF AIR ELUTRIATION, WATER SEDIMENTATION, AND
SINGLE COUNT OF GROSS SAMPLE

Air Elutriation											
Fraction	Linear velocity of air, mm./sec.	Wt. of total fraction, per cent	% Weight of particles of various diam.								Calculated average diameter, microns
			60	50	40	30	20	10	5	2	
1	8.7	17.6	..	..	..	..	2.0	6.5	7.18	1.90	8.2
2	11.3	21.6	..	..	..	4.6	10.5	3.9	2.13	.48	18.0
3	20.2	4.9	..	..	..	.9	3.0	.3	.61	.03	19.4
4	25.3	16.7	..	4.5	3.7	5.5	2.6	.34	.06	.03	35.6
R	..	39.2	16.7	11.1	7.3	3.2	.7	.07	..	..	50.2
Total		100.0	16.7	15.6	11.0	14.2	18.8	11.1	9.98	2.44	32.0
Water Sedimentation											
Fraction	Time settled, min.	Wt. of total fraction, per cent	% Weight of particles of various diam.								Calculated average diameter, microns
			60	50	40	30	20	10	5	2	
1	25	9.12	..	..	..	..	1.8	2.4	2.75	2.17	8.5
2	15	7.27	..	..	..	.2	1.4	2.2	2.56	.91	9.9
3	10	17.38	..	..	..	3.7	5.1	6.5	.83	1.25	16.3
4	5	23.06	..	1.7	13.3	3.8	2.4	1.4	.38	.08	37.4
R	...	43.17	13.4	10.7	8.5	6.4	3.2	.8	.15	.02	45.0
Total		100.0	13.4	12.4	21.8	14.1	13.9	13.3	6.67	4.43	32.5
Original Sample, Single Count											
Deter- mination No.	Wt. of total fraction, per cent	% By weight of particles of various diameters								Calculated average diameter, microns	
		60	50	40	30	20	10	5	2		
1	100	13.2	13.2	19.5	22.4	16.5	9.4	4.4	1.3	33.6	
2	100	18.4	18.9	15.2	17.1	19.0	7.2	3.3	1.0	24.9	
3	100	25.2	13.5	14.1	15.2	20.0	7.1	3.7	1.3	36.6	
Average		18.9	15.2	16.2	18.2	18.5	7.9	3.7	1.3	35.0	

TABLE V
DETERMINATION OF AVERAGE PARTICLE SIZE OF A MIXTURE
(1) By separate examination of the components of the mixture.
(2) By examination of the mixture.

Mixture No. 1											
Components No.	Wt. per cent	Wt. per cent of particles of various diameters								Calculated diameter, (microns)	
		60	50	40	30	20	10	5	2		
a	17.6	..	..	..	..	2.0	6.50	7.18	1.90	8.2	
b	21.6	..	..	..	4.6	10.5	3.90	2.13	.48	18.0	
c	4.9	..	..	..	.9	3.0	.30	.61	.03	19.4	
d	16.7	..	4.5	3.7	5.5	2.6	.34	.06	.03	35.6	
e	39.2	16.7	11.1	7.3	3.2	.7	.07	..	..	50.2	
Total (1)	100.0	16.7	15.6	11.0	14.2	18.8	11.11	9.98	2.44	32.0	

Mixture,											
Single count (2)	19.7	15.6	11.7	11.3	21.0	14.4	5.0	2.30	33.4		

Mixture No. 2

Components No.	Wt. per cent	Wt. per cent of particles of various diameters									
		60	50	40	30	20	10	15	5	2	
a	50	11.1	7.0	6.8	8.9	7.1	2.1	4.2	2.2	.6	35.7
b	50	..	..	..	5.8	5.2	7.0	18.6	9.7	2.6	12.5
a + b (1)		11.1	7.0	6.8	14.7	12.3	9.1	23.8	11.9	3.2	24.2
By single count (2)		9.6	10.1	10.1	17.4	16.3	..	17.4	13.7	5.6	25.9

Synthetic Mixtures

Due to loss of some 5 to 10% of material during elutriation procedure, further comparative work was done on synthetic samples prepared by mixing appropriate weights of elutriation fractions or other samples of varying degrees of fineness. These synthetic samples served as the un-elutriated material and a determination of the average particle size was made upon these samples for comparison with the value calculated from the average particle size determined on the various components of the mixture.

Table V shows the agreement obtainable.

Weight Calculated from Microscopic Data

As a further check on the method, the attempt was made to estimate the weight of the coal sample spread on the microscope slide. This necessitated determination of the total number of particles of various sizes. The usual method of procedure gives us the average number of particles of each size in a quarter of the field of the micrometer eyepiece. The area of this field for a given magnification is known. The area covered by the sample may be measured by means of millimeter ruled paper. The

weight of the sample is then $\frac{v\rho A}{f}$, where v is the volume of the particles in a quarter field, ρ the density of the material, A the area covered by the sample, and f the area of a quarter field. Obviously, $v=\Sigma nd^3$, where n is number of particles of diameter, d .

A known weight of material was put on the slide by the following procedure: A thin slide of dimensions 50 x 75 mm. is weighed on an assay balance; 0.002-0.004 g. of coal is placed on the slide and weighed. A drop of the Canada balsam-xylol mixture is placed on the slide and mixed with the coal by means of a fine quill, any material remaining on the quill being spread on the cover slide. The cover slide (50 x 75 mm.) is then placed on the drop and the slides pressed together and slid back and forth until the mixture is evenly distributed and covers an area of 1 to 2 square inches. Microscopic examination is made as previously described.

With very finely divided material this procedure gives a field containing too many particles per unit area for easy counting. In such a case, a Canada balsam mixture containing a known weight per cent of coal is made up in a weighing bottle and a known weight of the mixture placed on the slide. This latter procedure was followed in the determinations on sample IV in Table VI. The true specific gravity of the coal used was 1.815.

Considering the difficulties of the procedure, the agreement between actual and calculated weights is good. The calculated weight is always higher than the actual weight due undoubtedly to the fact that the procedure builds a cube around the irregularly shaped particles and thus indicates a volume larger than the actual volume. Since, however, the ratio b/a does not change progressively with change in size of the particle, the values for percentage weight of each size and for average particle size should agree with values determined by elutriation procedure.

In making the following measurements of length, breadth, and thickness, the sample was spread on the slide with xylol which was then allowed to evaporate. No cover glass was employed. The measurements of length and breadth were made by means of the micrometer eyepiece. Measurements of thickness were made by focusing on the top surface of the slide and then on the highest point of the particle. The difference in the two readings on the micrometer focusing screw was called the thickness of the particle.

TABLE VII
MEASUREMENTS OF LENGTH, BREADTH AND THICKNESS

Anthracite Coal					
Estimated edge	L	B	T	Average edge $\frac{L + B + T}{3}$	No. of particles measured
50	60	40	39	46	18
30	32	24	25	27	18
20	18	16	16	17	19
10	10	8	6	8	18
5	5	4	7	5	13
Bituminous Coal					
50	57	35	54	49	19
30	30	24	26	27	19
20	19	15	20	18	19
15	13	12	17	14	13

The dimensions given are numerical averages, and the average edge has been taken as $\frac{L + B + T}{3}$. This figure differs little from $\sqrt[3]{LBT}$

or from $\frac{\sqrt[3]{lbt}}{n}$, where l, b, t are dimensions of an individual particle and

n the number of particles measured, due to the fact that the dimensions are not widely different.

It will be seen that the average edge so determined is slightly less than the estimated edge determined by the visual method of "squaring" the particle as previously described.

Summary

The term "average particle size" is capable of various mathematical interpretations, many of which have little practical significance. The usual statistical method of calculation from microscopic data considers only the numbers of particles of a given size in determining the average diameter. Thus, the weight of a particle of a given diameter in the general average is determined by its frequency of occurrence or its numerical percentage of the total number.

In practice it is difficult to dissociate a particle from its surface or volume. We find other values for mean diameter when we substitute for numerical frequency of occurrence, the per cent of the total surface or of the total volume (or weight) represented by particles of the respective sizes.

The value for effective average particle size suggested for ceramic materials, fillers, and pigments is obtained from the following expression:

$d_{av} = \frac{y_s d}{100} = \frac{\sum n d^3}{\sum n d^2}$, where y_s is the per cent of total surface represented by particles of diameter, d , and n is the relative number of particles of diameter, d .

The value for effective average particle size suggested for use in problems of ore or coal concentration is $d_{av} = \frac{\sum y_v d}{100} = \frac{\sum n d^4}{\sum n d^3}$ where y_v is the per cent of total volume represented by particles of diameter, d .

These values for average particle size have practical significance. Thus mean diameters calculated from surface are related inversely to the specific surface of the material and are of value to ceramists and other workers where the total surface exposed per unit volume or weight of material is of importance. Mean diameters calculated from volume show the region in which the average weight of material is concentrated and are of value in problems of ore or coal concentration.

It is believed that microscopic measurement of the size of particles in a sample of pulverulent material may be employed in place of elutriation with a considerable saving of time. Data obtained by elutriation and microscopic measurement of pulverized coal have been submitted.

A rapid method of microscopic measurement has been described which gives results sufficiently accurate for many purposes, and should be of value to workers in ceramic materials and fillers. A subsequent article will discuss the extent of separation of mineral matter from coal at different degrees of pulverization.

Acknowledgments

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COAL AND COAL PRODUCTS LABORATORY
CHEMICAL DIVISION
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SCHEDULING IN A TERRA COTTA PLANT

BY PENSYL MAWBY

In order to understand the problems of control in a terra cotta plant it is necessary to know something of the industry itself. Terra cotta, or as the name implies, burned clay, is made by molding or modeling suitable clay into the desired shape and baking to secure hardness. The method is very simple in theory and in practice and has been used in all the ancient civilizations.

Terra cotta in some form has been found in the ruins of every seat of ancient culture. As early as 500 B. C. the Egyptians were making clay slabs, decorating them with some form of crude art, and baking them. The Greeks used highly decorated figures in their temples. Terra cotta for purely architectural purposes also came into use. However, the material evidently fell into disuse in the Dark Ages owing to the inrush of barbarism, as medieval records contain no mention of the product.

It can be truthfully said that the present age of the product dates back to only the last twenty years, for it is within that time that discoveries and refinements in process have been made which have placed its manufacture on a stable base, eliminated much of the wastes and other losses, and made it an industry capable of holding its own in modern competition. The terra cotta business is now on a firm foundation.

As stated before, the process is simple. Clay and ground bits of fine brick, porcelain ware, etc., called "grog" form the principal raw materials. The clay is taken from the storage bins and run through a continuously operated chain of machines known collectively as the mixer. In the mixer, the clay is first ground to a fine powder after which it is removed and sifted to eliminate all foreign matter. Grog and water are then added in the "pug" and the material thoroughly mixed. The clay comes out of the pug on a moving belt ready for use. If it is not needed for immediate use it is stored in bins adjacent to the main room until needed.

In the making of intricate pieces of artistic shapes and design, the clay is modeled by an expert modeler. In the case of pieces to be duplicated, the work is much similar to the work in a foundry. Suitable molds of collapsible type are made and the clay pressed into them by hand.

The pieces of terra cotta, whether modeled or molded, are not ready for the next step in the process until they have been allowed to stand and dry some thirty-six hours. After the pieces are dried, a chemical preparation, called "slip," or glaze, is sprayed on to produce whatever color or glaze effect desired. The pieces are now carried to the kilns where they are burned at a steadily increasing temperature for a period of from three to six days after which the terra cotta is ready to be inspected, fitted, and shipped.

Too much stress cannot be laid on the fact that this is essentially a hand labor one. Machines have not yet been invented which can supplant the

hand labor. It is also an industry which has very little standardization. With the exception of quality and workmanship, we may say it is entirely without standardization. Rarely are two buildings ever alike. The design differs, the plan differs, the color or finish differs and last, but not least, the size of the blocks vary. These factors make each job entirely different from that which preceded it, therefore, each job will require not only a different treatment but also a varying length of time to go through the factory. All these factors necessitate some adequate system of control. The superintendent, since he is able only to approximate the time needed, will want to know at all times just where his production is, if it is up to schedule and just what jobs need to be pushed. He should be able to plan ahead all the factory moves.

The system of control employed at present consists simply of having the foreman report to the main office on the form shown in Fig. 1 as soon as a section of the job, or order, goes out of his own department. No record is made of the date the section entered the department as it is assumed that this date will, in all cases, be the same as the date on which it left the preceding department. These "out" dates are then entered on

the form as shown in Fig. 2 and the form is placed in a loose leaf note book, kept in the superintendent's desk.

No attempts are made to schedule the work. In addition there is no way of checking the progress of production except by laborious review of the production book in the superintendent's desk.. Furthermore, the superintendent does not know whether the job is in production or not because, as was previously pointed out, the dates are entered after the production in that particular department is finished.

A scientifically constructed control system should require as little labor as possible for its operation yet provide the essential information necessary

FORM 61

TO THE SUPERINTENDENT

FOLLOWING SECTIONS PUT IN HAND OR OUT TODAY

DATE DEPT.

ORDER NO.	SECTION	IN	OUT		REMARKS

.....
DEPT. FOREMAN

FIG. 1.

to call the superintendent's attention to the items which need his attention. It is the writer's belief that the system proposed in the following pages will satisfy these requirements.

This system is composed of a main graph board constructed to hang on a wall in such a way that all parts are easily reached and the various devices changed. The backing is to be of wood of sufficient thickness to give stability and serve for a firm foundation. Covering the wood is a thickness of heavy cork linoleum into which pins can be pushed with little effort. This cork facing is painted white, without varnish. A frame at least three inches in depth should be provided to serve as protection, otherwise the various symbols might be brushed off. The accompanying blue print is to be used for reference. The boxed numbers

BUILDING					COLOR								
LOCATION					SURFACE								
ARCHITECT					ORNAMENT				SPEC. JOINT				
DELIVERY TO					EST. TONNAGE				EST. MOULDS				
ORDER		SECTIONS		ARCHITECTS DRAWINGS		REMARKS (FIG. 2)							
FEATURE		SECTION		NO. PIECES		D.O.	M&M	MOD.	P&F	KILN	FIT.	SHIP	DATE OF SHIP.
		A											
		B											
		C											
		T											
		U											
		V											

FIG. 2.

thereon refer to the numbers cited in these instructions. The caption headings, lines, divisions, etc. should be painted on the white surface in the proper places.

Under the caption "Order" as shown in the figure, are three columns marked "Number," "Section," and "Pieces." In these columns are brass name plates No. (1) constructed so that label cards may be shown in them. In those name plates in the column marked "Order" will be given the order number of the job. In the plates in the "Section" column will be the section letter of a portion of the order and in the "Pieces" column will be the number of pieces to that section.

The sections of the order then are shown between the horizontal lines across the board while the departmental divisions are shown by the vertical lines.

In a space between the "Pieces" column and the next, marked "Mod

"Making" are set tapes on spring spools as shown on the chart by No. (2). At the free end of each tape is a tack which will hold the end of the tape in position as it is drawn across the board through the departmental column to the right. Production progress of each section of an order through the various departments will be indicated by drawing the tape to the proper columnar position.

These columns, as is shown, represent the Model Making Department, Modeling Department, Moulding Department and the Pressing and

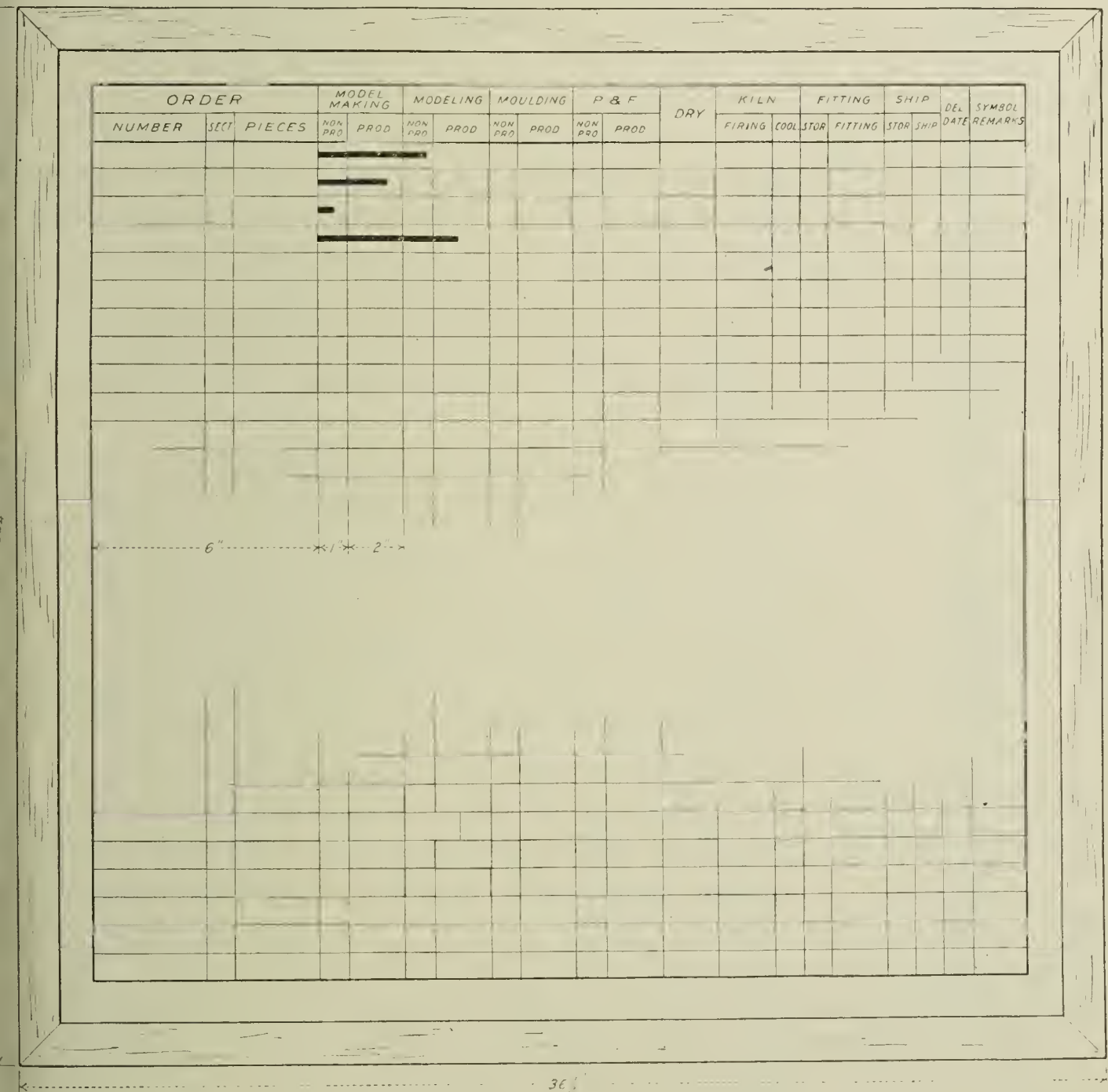


FIG. 3.

Finishing Department. It will be noted that these departments are subdivided into two columns, one marked storage, or "non-production," and the other marked "production." By using these columns it will be possible for the graph tape to show whether the section is actually in production or not in that particular department. It is also suggested that the tape be moved through varying degrees in the production column so as to show the progress of the work. For example, if the tape is drawn half

O R D E R			M O D E L M A K I N G		M O D E L I N G		M O U L D I N G		P & F		D R Y	K I L N		F I T T I N G		S H I P.		D E L. D A T E	S Y M B O L R E M A R K S
N U M B E R	S E C T.	P I E C E S	N O N P R O D.	P R O D U C T I O N	N O N P R O D.	P R O D U C T I O N	N O N P R O D.	P R O D U C T I O N	N O N P R O D.	P R O D U C T I O N		F I R I N G	C O O L . S T O R.	F I T T I N G	S T O R.	S H I P.			
111	111	111	(7)	(3)	(4)	(3)	(4)	(3)	(4)	(3)	(4)	(3)	(4)	(3)	(4)	(3)	(4)	(3)	
			(5)	(6)	(5)	(6)	(5)	(6)	(5)	(6)	(5)	(6)	(5)	(6)	(5)	(6)	(5)	(6)	

FIG. 4.

way across the production column in the Pressing and Finishing Department it signifies that the work is 50% completed here.

The next division, or column, is marked "Drying" and represents a non-production department. The kilns follow. This is also divided into two columns one for firing and the other for cooling in the kilns. The "fitting" is the last departmental column and is divided into "Storage" and "Shipping." If the goods are in process of shipping the tape is drawn into this column.

The tape should never reach the end until the section has been shipped in full. This is as far as the tape is ever drawn. When it reaches this point the section of the order is complete and the symbols, cards, tape, etc., removed and the space used for another section. A column has been provided for the notation of the delivery date as is shown on the figure.

A collection of colored faced thumb tacks should be provided. The colors should be seven in number. In addition to being colored, six of the sets should have numbers from one to thirty-one stamped on the faces. The other set is numbered one to nine. Each of the six colors will represent two months, e. g., January and July, February and August. The numbers will represent the date in the month. These date pins will be placed in the corners of all departments as shown in the Figs. 3 and 4. The work is scheduled through the factory and its various departments with reference to the final delivery dates. No. (3) represents the date on which the job is scheduled to go into the department while No. (4) is the date on which the job actually comes in. The columns marked "Symbol" and "Remarks" are reserved for symbols to show the reason for any delay and remarks on that delay.

The following is an example of how this chart would work. Order number 1432, Section A has been accepted by the plant for manufacture. It contains 132 pieces. The order number, section letter and the number of pieces therein are placed upon the board in the name plates. The proper delivery date is shown in the provided column. The work is scheduled

rough the various departments and the scheduled dates are shown by
ans of pins mentioned. Only "In" dates are shown since the "In"
tes of the following department should correspond to the "Out" dates of
e preceding department.

The tape advances into the Model Making storage column and the actual
n" pin is placed at No. (7) when the work is released from the draughting

ce. When production is
gun the tape is moved into

production column and the
ual "In" pin is placed at

. (4). Upon completion the
e is moved into the next

partment and the "In" pin
sted. Comparisons of the

o date pins will show
ether or not the job is up

schedule and if not, it will
ow exactly which depart-

nt is at fault. These com-
risons can be easier made

more pins are used. In this
se the "Scheduled In" pins

uld be placed at No. (3)
d the "Scheduled Out" pins

No. (5). A subtraction of
e two dates can easily be

de and the scheduled time
mputed. The "Actual In"

a would then be shown at
. (4) and the "Actual Out"

a at No. (6). In this way
t only can computations be

sier made but mistakes be
oided. The latter, or four

a method, will probably
ove the best since by it can be shown conditions impossible to show

isfactorily on the other, *e. g.*, when some pieces are advanced to the
xt department before the job is finished in the preceding. In this case

e "Actual In" pin will be placed in the second department as soon as
e first piece is worked on. The "Actual Out" pin will not be placed in

e first department, nor the tape advanced until the order is complete in
e first. If the seventh colored pins are numbered from one to nine they
n be placed in the space normally occupied by the tape, in the proper

FORM 61A

TO THE SUPERINTENDENT

FOLLOWING SECTIONS PUT IN HAND OR OUT TODAY

DATE DEPT.

ORDER NO.	SECTION	IN	OUT	S/A	REMARKS
		(1)	(2)	S	
		(3)	(4)	A	
				S	
				A	
				S	
				A	
				S	
				A	
				S	
				A	
				S	
				A	

.....
DEPT. FOREMAN

S = Schedule
A = Actual

FIG. 5.

combination, to show the number of pieces so advanced. This will save much confusion in practice. The four-pin system will also allow the condition of such sections to be shown which are finished in the preceding department, yet are being held in storage in the next department. The time would not be charged against this department as would be under the two-pin method.

One of the chief duties of the clerk responsible for posting of the board will be to see that orders are not falling behind the schedule. If this should take place, he will immediately place a red card in the symbol column. This feature is not to be neglected for it is one of the most valuable. It will serve to draw attention to this particular order section and the card should not be removed until the conditions are remedied. There is nothing at present, so far as the plans have gone, to prevent the officers on charge from scheduling more work in a department than its capacity will warrant. A small auxiliary chart will remedy this condition. A spring tape chart or graph, such as has already been described could be used. The four departments, modeling, molding, pressing and finishing and the kiln should be shown as were the orders and sections. The department space would be done away with and a percentage scale substituted. In this case the tape will be drawn across to the percentage of capacity which is scheduled for each department. Since the main chart will show exactly which orders are scheduled for that week it is not necessary to show this information on the capacity chart.

Some very slight changes should be made in the method of reporting. The present foreman's report should be made in triplicate in the main office. The date of report, department, order number and section should be filled in by the office clerk before being sent to the shop. He will also fill in the "Scheduled In" and "Scheduled Out" dates as shown on Figure 2 by the note figures No. (1) and No. (2). Two copies will then be sent to the foreman. The third should be kept on file. The foreman will enter the "Actual In" date at No. (3) when the section starts production in the department and send the report to the main office immediately for entry. When the section is completed the foreman will enter the "Actual Out" date at No. (4) and send the form into the office. It should be noted that these forms must be sent to the foreman several days before the section is scheduled to start that the receipt will serve as an order to produce. These reports will, of course, serve as the basis for entry on the main board.

It will not be necessary to make any other entries because the board will give all information at the time. However, the form as shown in Figure 2 could be kept as a permanent record. The dates of "Scheduled In," "Scheduled Out," "Actual In" and "Actual Out" should all be kept instead of only the "Actual Out" date as is done at present.

The advantages of the proposed system are obvious. The work can be scheduled more closely to maximum output in the various departments and in addition each department will know exactly how it stands and what work is ahead. The superintendent can tell at a glance how production is progressing and know which sections or jobs need his attention. It will not be necessary for him to review a mass of figures in order for him to know the conditions.

Under the proposed system of control, the work is anticipated and the foreman and men can make good use of the advance information. There is every reason to believe that a friendly rivalry will spring up between departments and an attempt made to prevent orders being delayed. This stimulation certainly would be healthy.

Another advantage is that each foreman will receive a written order as his authorization to proceed. Likewise he will be relieved of the necessity of planning orders, a function which essentially belongs to the management.

Not only are all the advantages derived in the plant itself, but some will be found on the outside. There is much less chance of running over delivery dates which in itself is a very important item. A plant which has the reputation of shipping the goods when promised has a reputation of which to be proud. It is expected that this proposed system will make a missed delivery date less probable. It is the writer's belief that the problem of control will not end here. More problems will come up as time goes on, among which will be problems of standardization in the industry, time study and scientific piece work rates.

KETCHAM TERRA COTTA COMPANY
CRUM LYNNE, PA.

HOW TO INSTALL AND OPERATE A FUEL OIL SYSTEM

BY JAMES D. LALOR

There are many sides to oil burning which a manufacturer never considers but I will confine my paper to the following:

1. How to install a fuel oil system to meet the requirements of the Board of Fire Underwriters so that you will obtain the lowest rate of insurance on your plant and insuring continuous operation.

2. The proper type of system to install to insure a good product with the lowest possible expenditure of power and fuel.

There are few men who know how to meet these requirements.

In laying out a fuel oil system, the first thing to do is to locate your tanks and pumps. These should be located in the lowest part of the property so that if the containers break, there will not be the slightest possibility of the oil flowing to any part of your property or that of your neighbor.

The tanks should be placed (when possible) at least 6 feet below the lowest pipe in any of your buildings. The pump suction should be 3 feet higher than the top of the tanks, and the main oil line from the pump to the buildings should have a pitch of about $\frac{1}{2}$ -inch in 10 feet to the point at which it enters the buildings, and where it enters the pipe should be at least 2 feet below the surface of the ground. All fuel oil lines will drain back automatically to the fuel tanks when the pumps are shut down and the system not in service.

The Rules of the National Board of Fire Underwriters state that fuel tanks shall be buried. I want to take exception here to that ruling. I say that fuel oil tanks should be put in concrete pits with sufficient room to walk around them, and if not in the building, to have a shed over them with open sides to protect them from the weather.

In the average plant, you will find more or less made ground or cinder fill. In spite of anything you can do, this will attack the iron in a short time. Then you will have leaky tanks, and your oil will seep away through the ground. In one instance of which I know, it found its way to the deep well from which the sprinkler tanks were filled. Upon examination of the sprinkler tanks, it was found that they had ten or fifteen thousand gallons of fuel oil in place of water. Therefore, leaving out the monetary loss, you are taking the chance of having it get into other parts of the property and causing considerable trouble. So put your tanks in a concrete pit where you can see them and examine them, and know exactly what is happening. In case of a fractured or a leaky tank, your oil can go into the pit and you can repair the tank at small cost.

All oil as it leaves the refinery contains more or less dirt, and when the oil leaves the tank car, it should run by gravity, or be pumped into an open strainer situated on the top of the tank (Fig. 1). The inside of the funnel should have a large removable basket strainer, which, when it becomes filled

with foreign matter, can be lifted out and dumped and put back into place without removing the body. In case heavy oils are used, it is a good plan to have a steam coil in the bottom of this strainer to warm the oil so that it will flow readily into the tank. When not in use, this strainer should be covered.

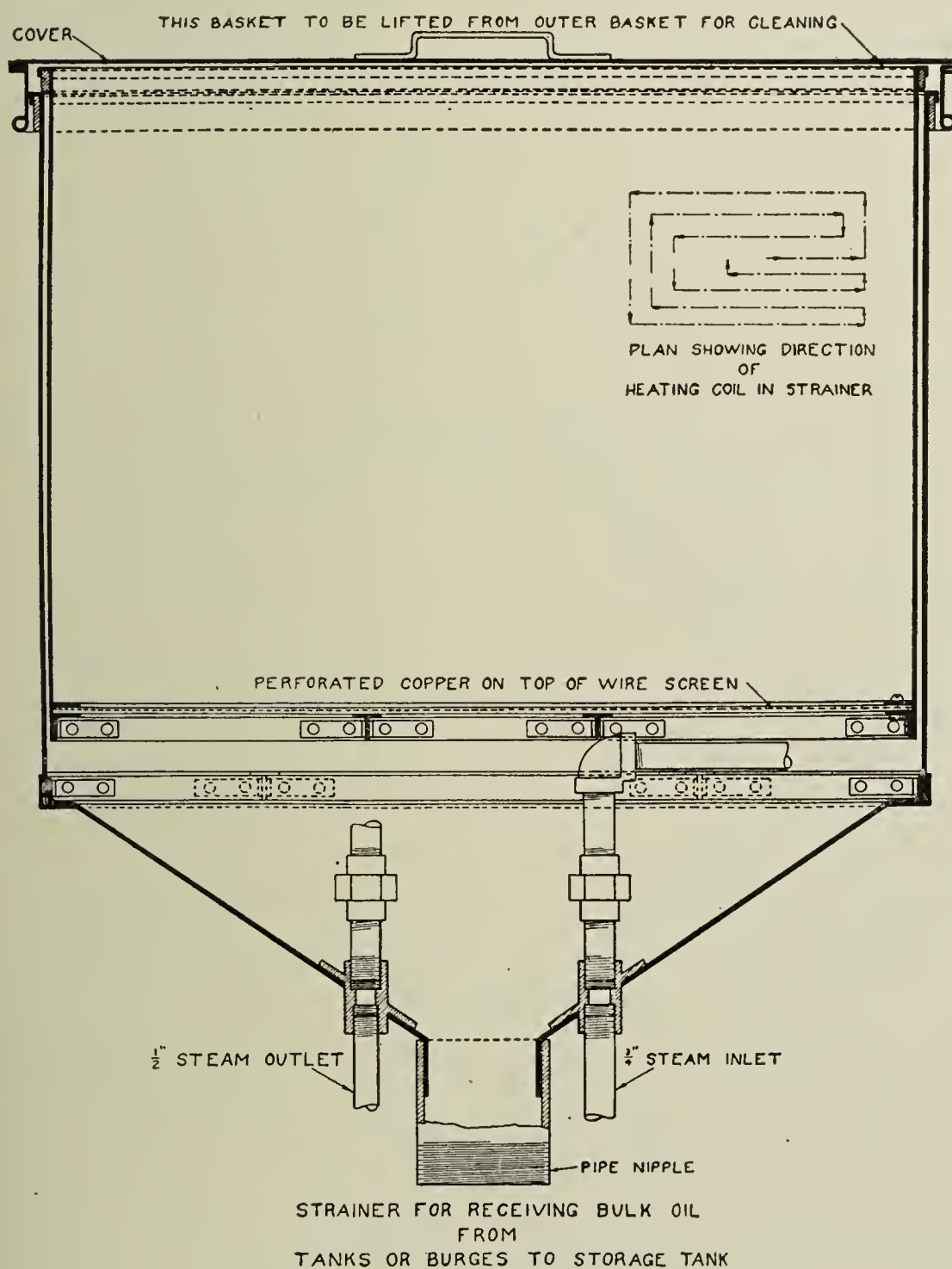


FIG. 1.

Many plants have a large filter press; the oil is received in tank No. 1 and pumped into tank No. 2 through the filter press, which removes anything that might possibly pass the large open strainer (Fig. 2).

All fuel oil tanks should be vented to permit escape of air when being filled. This vent pipe should be at least 3 feet higher than the highest

point of fill, which in the average plant would be at the top of the tank car.

Since the cold weather often affects the handling of fuel oil, it is very wise to put a heater in the tank (Fig. 3). There should be a sheet iron casing like a barrel, openings cut in the side to allow the fuel oil to flow in around the coil, a thermostatic control, so that the oil is never heated to more than 110°F . The oil will always pump readily at this temperature. As not more than the equivalent of 2 or 3 barrels of oil will be heated to this temperature, the amount of heat required is small. Twenty-five gallons an hour can be heated to this temperature on about one square

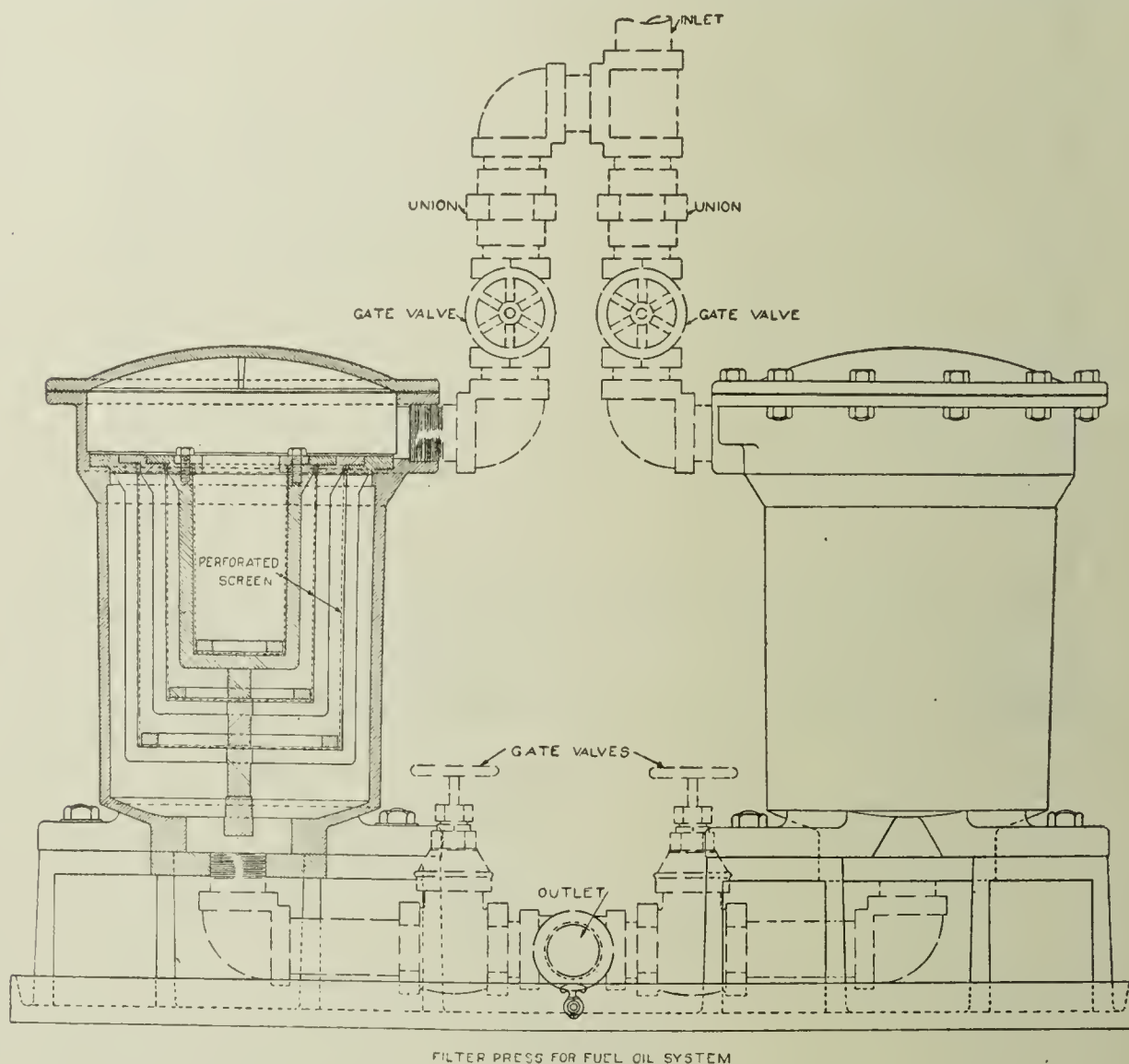


FIG. 2.

foot of heating surface, with a pressure of about 5 pounds of steam. This eliminates the danger of gasification of the oil.

The suction to the pump should be made in one piece, passing through the top of the tank, no joints or connections being within the tank itself. This is done to eliminate the possible leakage of air into the suction line. The bottom of this pipe should be about 6 inches above the bottom of the tank, the end plugged and having perforations in the sides equal in area to the size of the pipe. This prevents possible lifting of any water that may collect in the tanks.

A fuel oil tank should be set 4 inches lower at one end, so that the water contained in the oil can settle to the lowest part and be pumped out from time to time as it may be found necessary. It is recommended that a half-inch pipe be run from the top of the tank to within one half-inch of the bottom and connected to a hand-pump outside the pit to remove this water. This line should always be at the opposite end of the tank from the main feed or pump suction. This prevents water getting into the

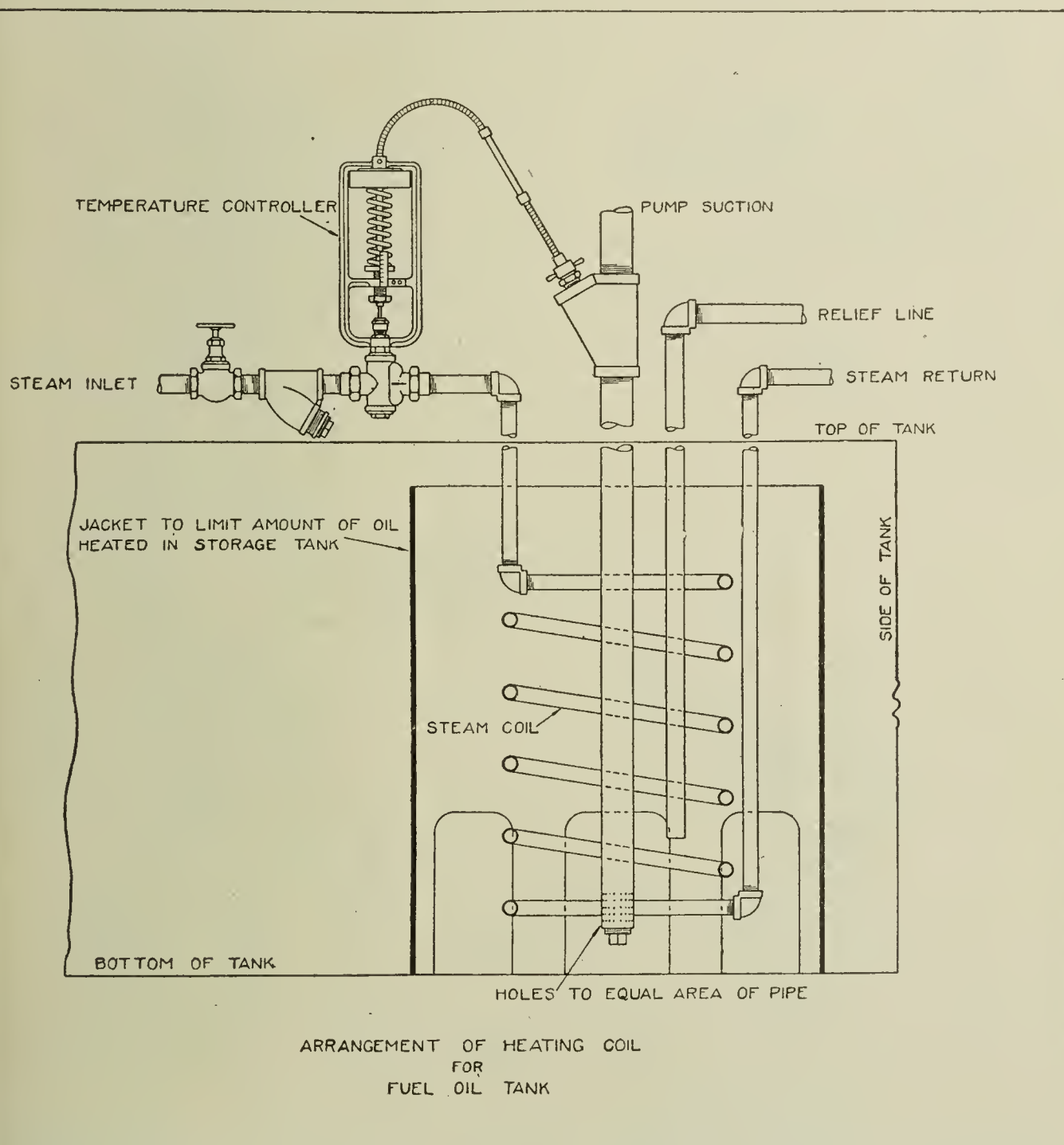


FIG. 3.

system causing sputtering and possible injury to the furnace or operator. Fuel oil, as a rule, will contain about $\frac{1}{2}$ to 1% of water from a leaky steam line in the receiving tanks or in the tank car when the car is filled at the refinery.

The pumping system here shown is beyond all question the best adapted for fuel oil. The triplex pump prevents the flooding of a system in case of

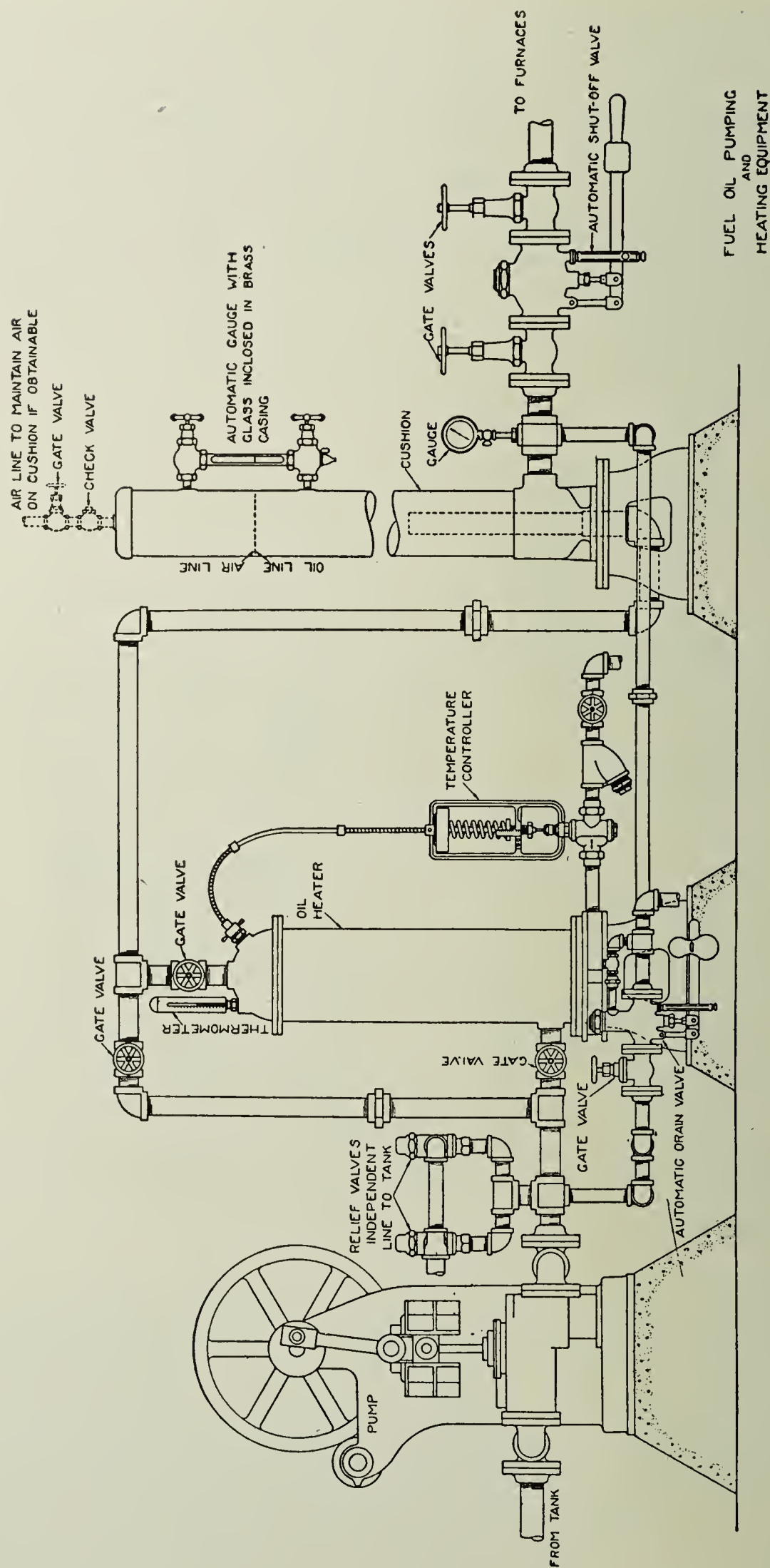
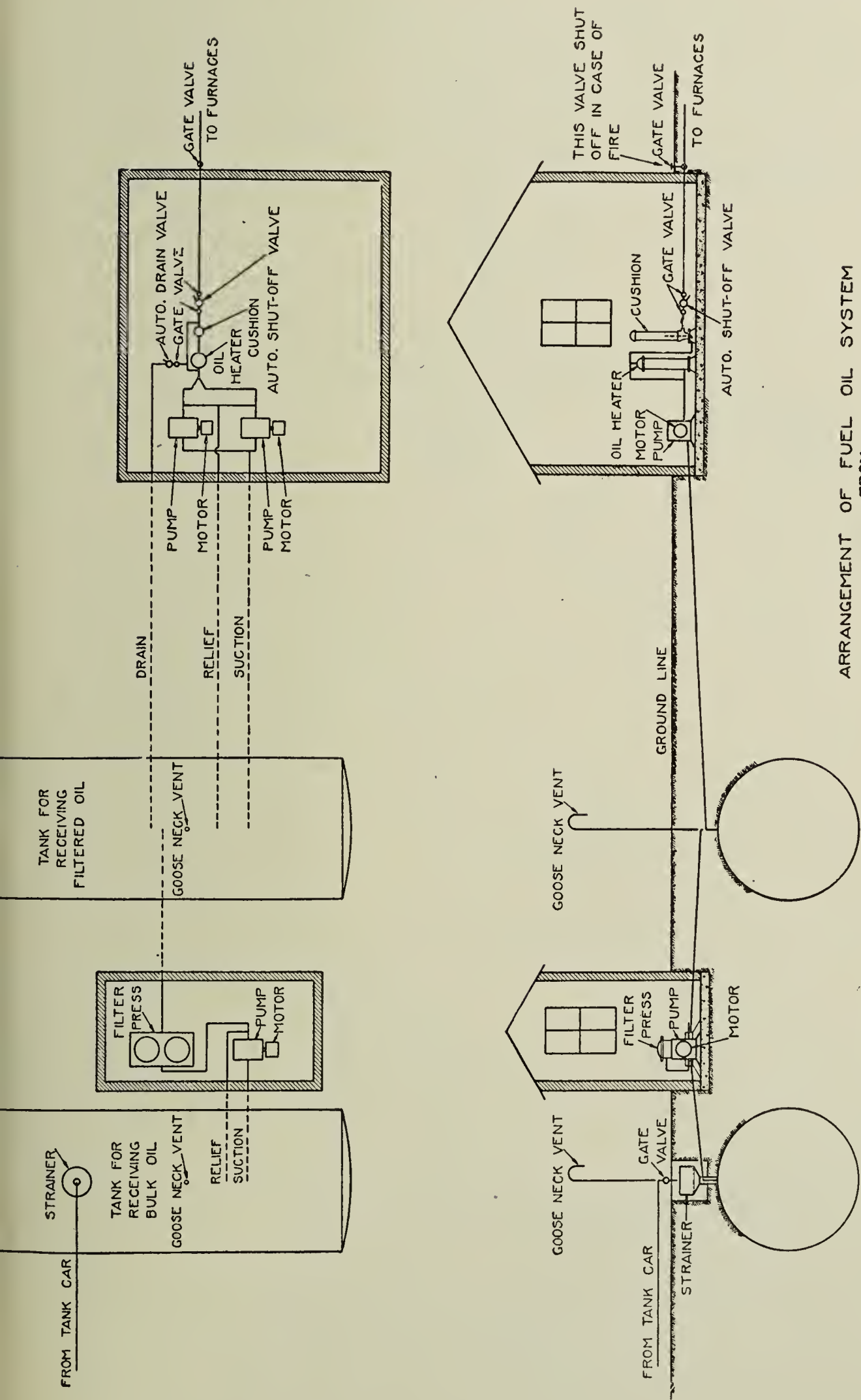


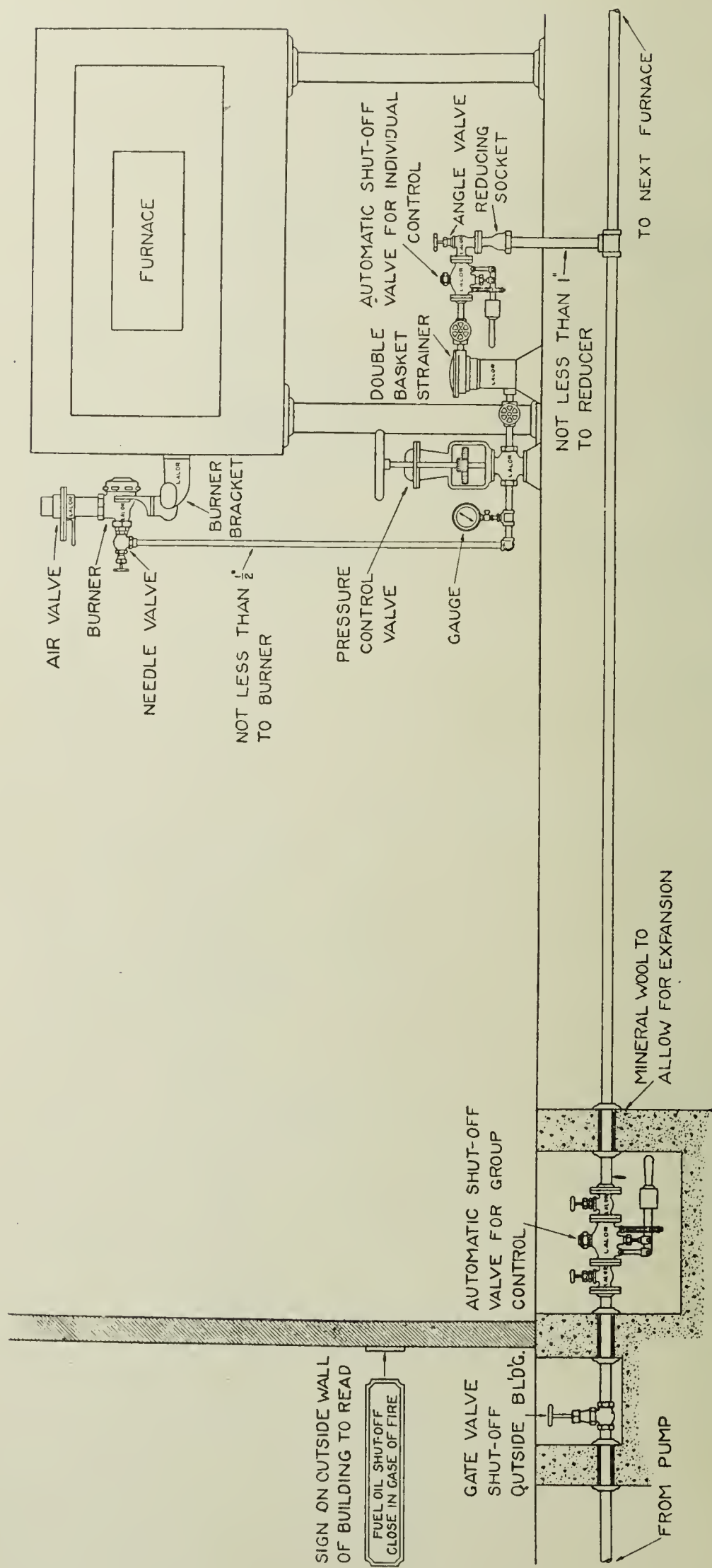
FIG. 4.

FUEL OIL PUMPING
AND
HEATING EQUIPMENT



ARRANGEMENT OF FUEL OIL SYSTEM
FROM
TANK CAR TO FURNACES

FIG. 5.

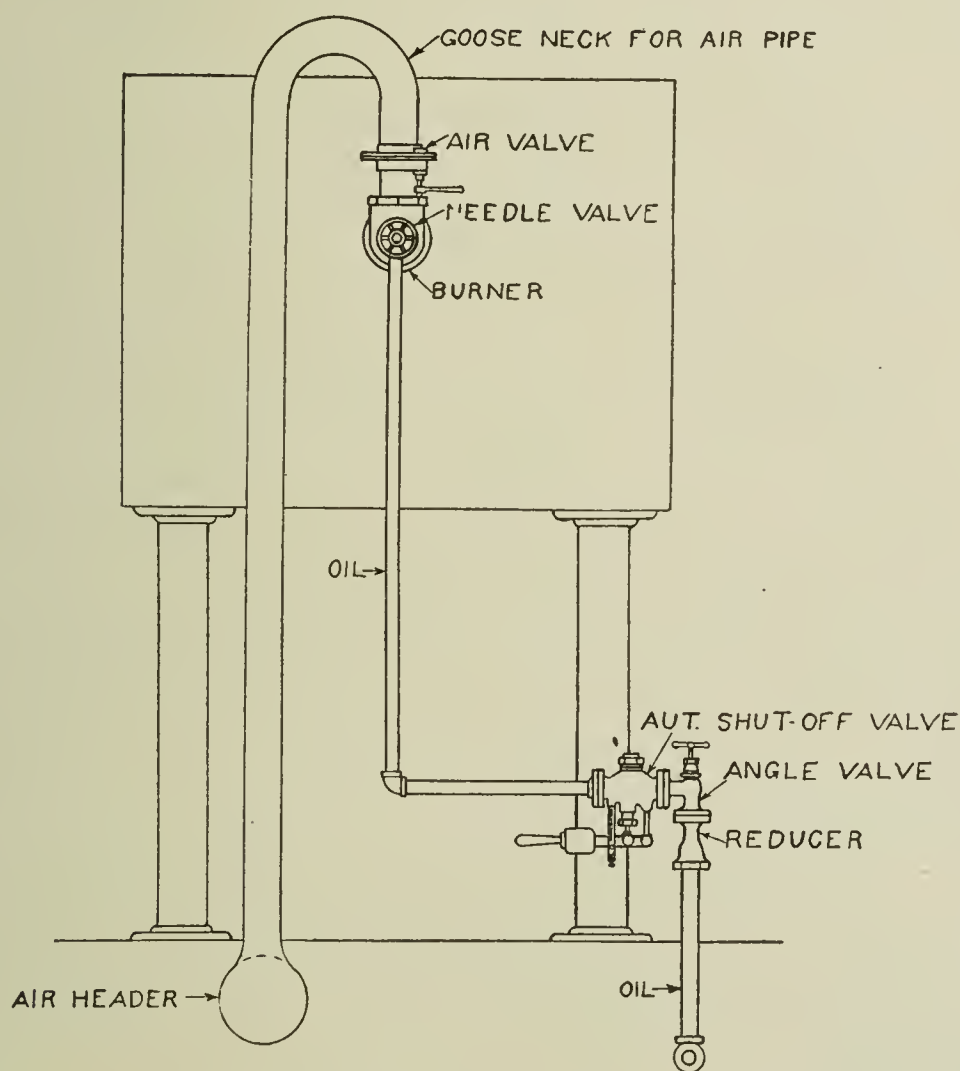


METHOD OF INSTALLING
EQUIPMENT
FOR
FUEL OIL SYSTEM

Fig. 6.

a broken line. The capacity of this pump should never be larger than twice the maximum oil consumption. There should be two pumps, and each pump should have two relief valves draining directly back to the tank. The heater should have a thermostatic control to prevent the oil from becoming warmer than within 25° of its flash point.

A cushion or accumulator maintains a steady pressure on the line and an automatic shut-off valve is advisable to insure against a loss in case of a ruptured oil line.



METHOD OF INSTALLING
GOOSE NECK IN AIR PIPE.

FIG. 7.

A drain valve is placed at the lowest point of the system and connected back to the fuel oil tank, so that the oil will drain automatically from the system when the pumps are shut down.

Figure 5 is a typical fuel oil system. There are two tanks in the ground, the receiving strainer, the vent, the filter press for clarifying the oil, the using tank, the pump, heater, cushion and accumulator, automatic

shut off and drain valves. All the lines pitch back to their source of supply so that they can be thoroughly drained.

Figure 9 shows how the lines should be laid out where there are a number of buildings in the plant.

Figure 6 is a typical plan of how an oil line should enter the building. The manual shut-off valve outside of the building in the pit has a plate over the valve, and a sign, "Fuel Oil Shut Off, Close in Case of Fire." This should be conspicuously displayed, with a red light over it at night when the plant is in operation. The ferrule in the wall is shown with the group control inside of the building; the lines under the floor; the method of tapping off the risers and carrying the lines to the furnace with the automatic shut-off valve protection, the air lines to come from overhead.

If the air lines are under the floor, they should be attached to the burner with a goose-neck (Fig. 7) coming up, so that no oil which should accidentally leak out of the burner could possibly pass into the air lines. If this should happen when the fans are started, the oil would be blown into the furnace, causing it to flash. The gas would explode in the air line, and probably set the building on fire. No oil piping under the floor should be less than 1 inch, and all risers should be of the same size until they extend to a point 12 inches above the floor line. This is required so that they will not easily be broken by moving equipment. From this point on, the lines can be $\frac{1}{2}$ inch to the burner, but no piping in any part of the system shall be less than $\frac{1}{2}$ inch in size, and this $\frac{1}{2}$ -inch pipe shall run directly to the burner, and the burner connection shall be at least of the same size.

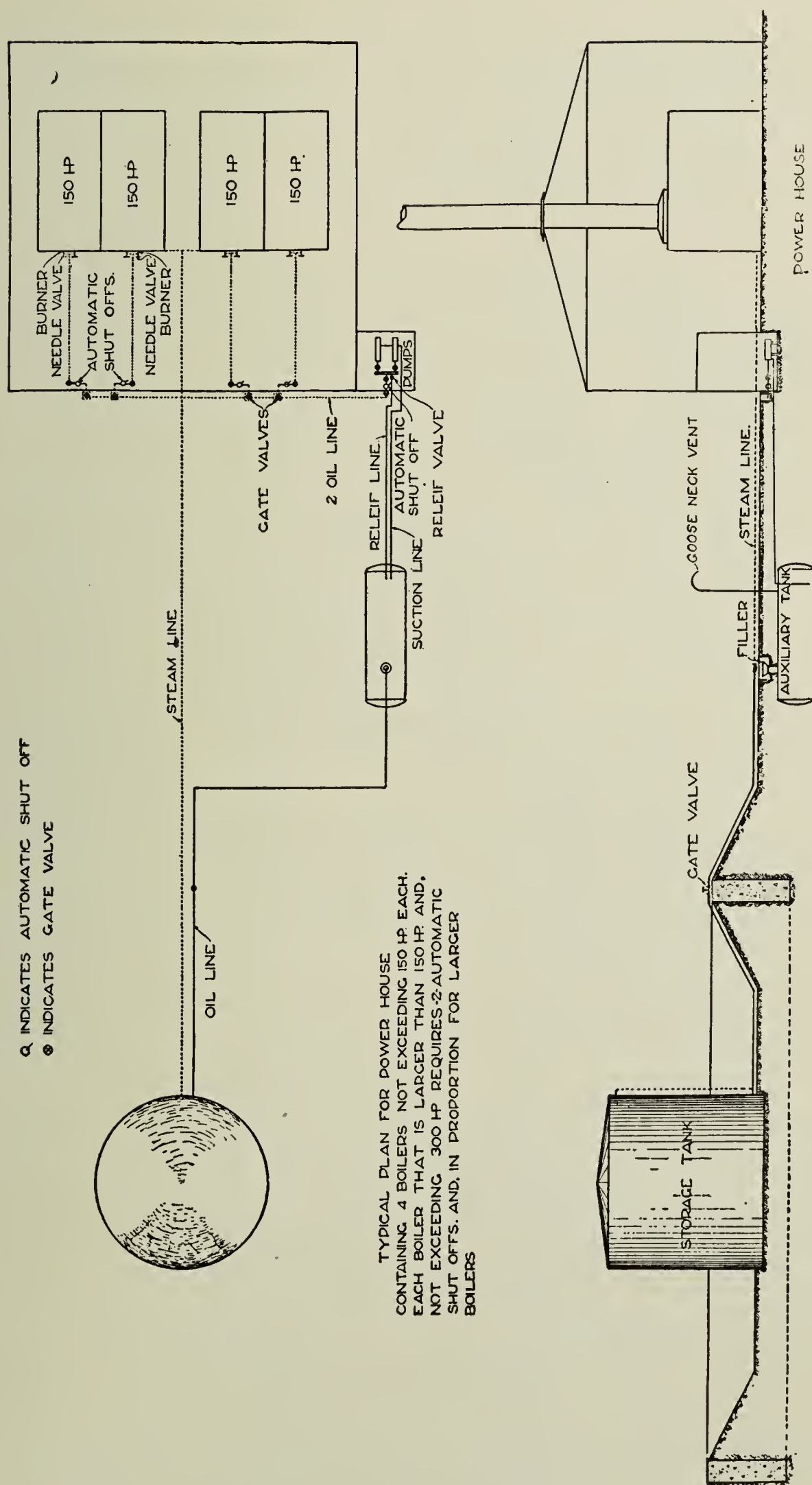
Those putting in fuel oil systems, should look very carefully into the construction of the relief valves of which there should be two, one of them for emergency. They should be constructed strong enough to stand the pressure which they control and should never have exposed adjusting screws. An oil-tight cap should cover these adjusting screws to prevent leakage, and also to protect them from being tampered with by employees.

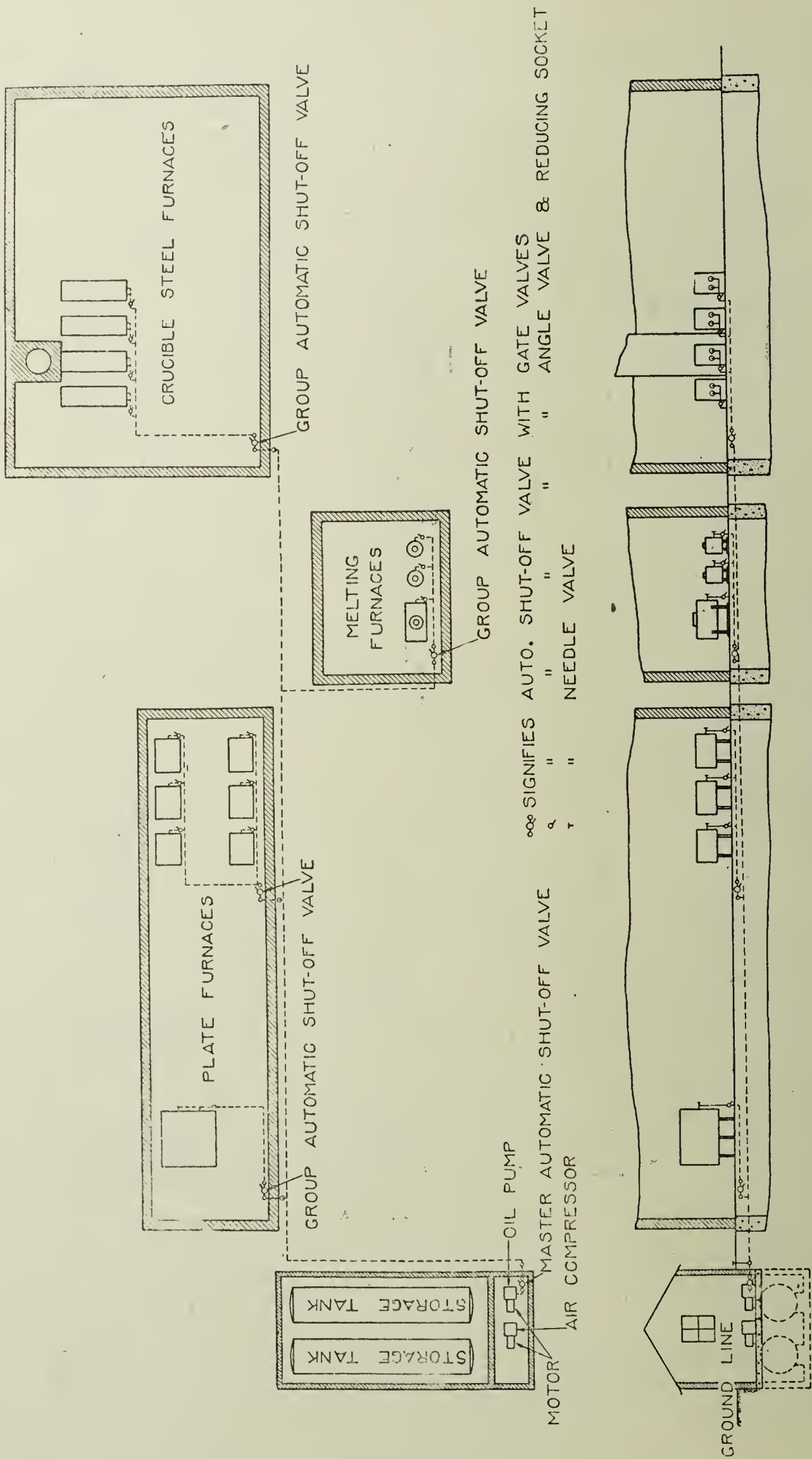
Strainers are important. They should be made of bronze with copper screens, and all joints should be metal to metal, bolted or riveted, and not soldered, so that any foreign matter lodged in the perforations can be burned off without injury to the strainer.

Where strainers are used on high pressure systems, the cloth bag type will eliminate all fine particles of scale or sand from pipes, fittings and tanks. They should be of the double type, cross-connected, so that one can be cleaned while the other is in operation.

Oil strainers on a system are extremely dangerous if the strainer is not protected by an automatic shut-off valve, as the operators are liable to open the strainer while pressure is on the line, or may turn on the oil before a strainer is properly closed.

**SAFETY FUEL OIL SYSTEM
BOILER AND FURNACE INSTALLATIONS.**





PUMPING SYSTEM
FOR
FUEL OIL

In an installation of a fuel oil system, galvanized piping should never be used—only black iron piping, and it is advisable that extra heavy cast-iron fittings be used throughout the construction. All joints should be either sweated or put together with freshly mixed litharge and glycerine, and this composition of such an age that it will harden in 20 minutes when exposed to the air; any mixture exposed to the air more than 20 minutes should never be used.

Gravity, loop, or return systems should not be installed.

In regard to the cushion or accumulator used on a fuel oil system, it has been known to hydraulic engineers for a number of years that the only way to stop hammer blows in a water line is to put in a cushion or accumulator, so the water enters from the bottom and discharges at right angles to the flow and is cushioned by the air at the top. This effectively prevents the hammer blows which often break fittings. These accumulators can be home-made. They should be provided with automatic gauge cocks. It is known that oil will absorb air, and some means of supplying air to the accumulator should be provided. If the air in the plant is under a greater pressure than your oil pump is producing, the connection should be made at the top of this accumulator with a needle valve and check valve, so that no oil could possibly pass out of the accumulator and into the air lines in the plant. Once or twice a day the air should be replenished in the accumulator.

Many plants install special motor compressors for supplying this air, as here shown. It costs very little to operate these motors, as they will not operate more than 10 minutes a day, and the first cost is the only consideration. A steady pressure means efficient burning, and without it, this cannot be obtained.

LALOR FUEL SYSTEM COMPANY
BALTIMORE, MD.

Discussion¹

By C. J. HUDSON:—In reading over Mr. Lalor's paper "How to install and operate a fuel oil system" the predominant impression gained was that a fuel oil system is dangerous, intricate and something to be avoided if possible. During periods of coal shortage the thoughts of many people are turned toward fuel oil for a solution of the fuel question. Probably Mr. Lalor had in mind, when writing his paper, only helpful suggestions for the fuel oil user and he wished him rather to be fully aware of the precautions necessary for a successful installation than to discourage him with complexities. So it is hoped that a review of Mr. Lalor's paper, together with some of our own experiences, may be encouraging to one who is thinking of installing a fuel oil system.

The requirements of the Board of Fire Underwriters are simple and

¹ Received November 20, 1922.

effective. These can be readily obtained, together with the state laws, from local insurance companies. There is nothing about these laws which should deter one from making a fuel oil installation but they ought certainly to be known before the installation is started.

There are many concrete oil storage tanks in successful use. These are probably not subject to the kinds of corrosion that befall the iron tanks of Mr. Lalor's experience. At Norton Company an underground concrete tank of 100,000 gallons capacity has been in successful use for over two years. Where heavy oils are used there is little possibility of leakage.

Crude oil may contain a considerable amount of dirt. From the oil wells to the user, through the various distillation processes, this dirt has an opportunity to settle out every time it is allowed to remain in a tank. Therefore the amount of dirt which finally reaches the consumer should be small. An open strainer through which the oil must pass to enter the storage tank is a wise precaution, but the filter press suggested by Mr. Lalor seems an unnecessary piece of equipment. There should be strainers in the line to catch any sediment which might plug it. Our system contains three sets of strainers working satisfactorily. One set strains the oil on the suction side of the pumps, one set is on the oil line and the final set of finest mesh is at the burners. The strainers are not considered "extremely dangerous" in any way. They are not protected by automatic shut-off valves. We have not found any need for burning out these strainers. The usual custom is to wash them in kerosene oil twice a day.

Provision should be made for heating the oil. Most fuel oil cars are provided with heating coils. Heavy oils, 12 to 16° Baumé, must be heated in order to permit them to flow from the car in cold weather. Heating coils should be placed in the storage tank, around the intake pipe and a steam line should parallel the oil line from the tank to the burners. The temperature to which the oil is heated just before entering the burners is quite important or at least it is necessary to maintain this temperature with small fluctuations. The reason for heating the oil is to lower the viscosity and thus facilitate atomization. If the oil temperature is fluctuating the flame will not be steady and will require frequent adjustment of oil and air (or steam) valves. Our system is provided with automatic temperature and pressure controllers. It is our belief that they should be installed on every oil system.

The cushion or accumulator recommended by Mr. Lalor is not a part of our equipment. We are not troubled with hammer blow and can see no use for such a piece of equipment except possibly in a system where very light oils are in use or where there is no return.

Mr. Lalor writes "Gravity loop or return systems should not be installed. Perhaps he meant to have left out the word "not," for by all means return system should be installed. No return means that there must be

dead end on the oil line. This means that the oil becomes stagnant at this dead end, so therefore becomes cold and the last burner on the line will not get the hot oil necessary for proper atomization. Another serious defect to a dead-end system is that an adjustment to one burner means a change on the other burners because the oil pressure on the line is thereby changed. This latter defect may be the reason why Mr. Lalor recommends accumulators.

Our oil system is installed on a Dressler tunnel kiln. A few difficulties have been experienced, but these must be expected with most any new equipment. When the causes of the difficulties were found, no time was lost in correcting them, so now we feel that fuel oil is an ideal source of heat, especially for a Dressler kiln.

The oil in use is asphaltic base of 14 to 16° Baumé, and about 19,500 B.t.u. per pound. Its viscosity is low. The oil is maintained at about 100 pounds pressure and atomized with air at 30 pounds. The oil temperature at the burners is maintained at 85°C. About twice as much oil is pumped through the system as is burned, the excess being allowed to return to the storage tank.

Water was at one time discovered in our storage tank. This was pumped out by means of an ordinary hand pump. The only other serious difficulty has been due to oils of high viscosity. The burners of our kiln are about 4 feet long and consist of an oil tube of small cross-section surrounded by suitable pipes for carrying air for atomization to the tip and water for cooling the burner throughout its length. With oils of low viscosity a pressure of 40 pounds will give satisfactory results, but a pressure of 100 pounds, the highest our system would stand, would not give a sufficient flow of the very viscous oil through burners of this type without shutting off our return. It is possible that a viscosity specification is not necessary for the sort burners required on periodic kilns, but it is believed that if the less viscous oils can be obtained without difficulty it would be an advantage. The viscosity specification which we have found necessary for best results from our particular installation is that 200 cc. at 110°C shall take not more than two minutes to pass through a standard Engler viscosimeter. The gravity of a fuel oil and its viscosity are not related.

Our experience has taught us that fuel oil is an ideal source of heat if its temperature and pressure are kept constant. These two controls are indispensable, but fortunately it is easy to maintain them constant by means of automatic instruments now on the market for these purposes.

FUEL OIL AS APPLIED TO PERIODIC UP-DRAFT KILNS IN THE MANUFACTURE OF HIGH TENSION ELECTRICAL PORCELAIN

By L. H. BROWN

The following paper is not intended to serve as a complete list of last word procedure to be followed by prospective users of fuel oil, but may serve as a slight assistance to someone who, under similar circumstances, is compelled to make a complete change of burning equipment in a comparatively short time, as was necessary at the plant of the R. Thomas and Sons Co., East Liverpool, Ohio, during the late fall of 1920.

Business conditions at that time were of such a nature as to preclude any possibility of an exhaustive experimental study of the subject, and the question resolved itself into one of obtaining *something* to burn, and not efficiency. The general layout of the plant does not lend itself readily to the use of coal—in fact, but three of the twelve kilns could be fired advantageously with coal.

The initial storage equipment consisted of an immense concrete tank buried completely below the level of the railroad spur. The tank was divided into two compartments of a combined capacity of 125,000 gallons. The bottoms of both compartments were sloped sufficiently to allow sediment and water to be drained off through drain cocks at will, and ventilators of 3-inch pipe were carried above the level of the adjoining building to carry off the volatile constituents which might rise in the event that the oil be overheated by the preheater. No protective coating of any kind was used on the inside of the tank.

The preheater consisted of a coil of $1\frac{1}{2}$ " pipe, and was 3 feet square and 4 feet high, located at the end of the intake pipe about 4 inches from the bottom at the shallow end of each tank. A T-connection from the pump with two valves enabled them to draw from either compartment at will. Steam at 80-pounds pressure could be used whenever desired, but it was never necessary, either in the winter of 1920 or 1921, to use steam at all in this tank when 24-26 Bé oil was used. It must be borne in mind that this tank was utilized merely as a storage reservoir.

A Weinman cylinder pump, manufactured at Columbus, Ohio, forced the oil from the storage tank to the operating tank in the plant proper at a 30-foot higher elevation. This pump (2" diameter by 4" stroke) operated successfully with a direct connected one-horsepower motor (Fairbank Morse) and delivers about an average of 15 gallons per minute. By-pass connections and valves permit of complete draining of the supply line after the pump is shut down. This pump is located on the top of the tank.

Oil for the kilns is pumped from the operating tank, which is located within the main plant and buried beneath the floor level. This tank is also of concrete and is of 6,000-gallon capacity. It was likewise provided with sloped bottom and drain cocks for the removal of water and sediment.

to piping whatsoever was submerged in it, except the pump intake, as the reheating was accomplished by a separate unit.

The pump supplying the kilns is a remarkably efficient and reliable outfit with an upkeep cost of practically nothing and a low power cost. It is handled by the Schirmer Company of Cleveland, Ohio, is known as the Sinking Pump, and operates on the centrifugal principle, delivering oil without the pulsation so often contended with in some cylinder pump installations. Pump and motor ($1\frac{1}{2}$ h. p.) are direct connected, and it is almost unbelievable that so small an apparatus can operate so continuously and efficiently. It has been known to build up a pressure of 80 pounds when the steam supply failed and the resulting increased viscosity of the oil brought about greater resistance. A maximum delivery of 10 gallons per minute is guaranteed on this particular size of pump.

Strainers connected in parallel remove coarse material from the oil after leaving the pump. Oil passing through these strainers enters the reheater at the bottom, rises through coils surrounded by steam (80 lb.) in the jacket, and emerges at the top where its temperature and pressure are shown by appropriate gauges.

Steam in the jacket enters at the top and the condensate passes out through a trap at the bottom. The National Supply Company of Chicago, Ill., furnish preheaters of this type.

The entire capacity of the pumps is scarcely ever used, therefore an adjustable by-pass arrangement was introduced at the point where the hot oil emerged from the preheater. Some excess oil was diverted back to the tank at this point, and gradually raised the temperature of the supply, the maximum temperature being controlled by a thermostat. Depth gauges operating on the inverted bell principle do not indicate properly on a tank installation of this kind, unless equipped with temperature variation compensators.

No piping smaller than 1-inch was used on any part of the installation except at the burner connections where $\frac{3}{4}$ -inch pipe was used. After this system had been in operation several months it was noticed that material was depositing on the pipe wall to a considerable thickness and would occasionally loosen, pass along and clog the burners. It is a question whether the use of smaller pipe with a resulting higher velocity would decrease the tendency to deposit.

All oil connections were made upward to the burners, to safeguard against leakage of oil into the air ducts.

The burner equipment consisted of Leader-Furnace Equipment and Taxon-Premix Burners, both types being designed for the use of gas and oil. The change from one fuel to the other can be made within a few moments without interfering with the firing. A fire-brick wall was laid at the front of the ash pit, allowing three half-brick air passages in the first

course and a 4" x 4" opening 6 inches from the bottom, for the burner. The burner tip is at least 36 inches from the ends of the radial flues.

Several different types of combustion chambers were tried, but with little success, as most of them tended to restrict the heat in the fire-box with a rapid deterioration of fire brick as a result.

One kiln installation was made using carborundum brick at the ends of the radial flues but corundite brick were later found to be just as satisfactory and considerably cheaper. When properly laid, that is, with a good joint, very little trouble is encountered.

The air is supplied to the Leader-Furnace Equipment Co. burners by a Spencer Turbo-Compressor direct connected to a (10 h. p.) motor. A five-ounce pressure is sufficient for normal conditions although the fan has a considerably higher rating. The air ducts are uniformly 8-inch diameter galvanized sheet with the exception of the kiln and burner pipes, which are slightly smaller. Butterfly dampers are placed at every kiln connection and serve as another point of control.

Air for combustion in the Maxon Equipment is supplied by a Maxon Premix rotary blower, 18 inches in diameter, and driven by a (3 h. p.) motor. This equipment furnishes the air supply for two kilns equipped with the latest Maxon burners. It delivers the air at a maximum pressure of three ounces to the sixteen fire-boxes.

Both types of burners are supplied simultaneously by the same oil pump but a higher oil pressure is required for atomization in the Maxon burners than in the other type. It has been found that atomization is more complete with pressures between 30 and 40 pounds when the Maxon is being supplied, but scarcely more than 15 pounds pressure is required with the Spencer burners. This, however, is not a disadvantage in this particular installation as the higher pressure can be carried whenever those particular kilns are under fire.

The following figures are only approximate but may give an idea of the comparative cost of firing a 16' 0" diameter kiln, 14' 2" to the shoulder. This size of kiln is never fired in less than 72 hours for economy in firing time usually results in incompletely vitrified ware. When fired with Pittsburgh coal using removable grates, such a kiln usually requires 12 to 13 tons of coal and will ordinarily consume 225,000 cu. ft. of natural gas when equipped with the old fashioned gas burner. With the present equipment a consumption of 2200 gallons of 24°-26° Bé. refinery residue gives very good results.

An examination of results over a long period of time shows clearly that oil firing is a decided success and profitable. There are, however, difficulties which will be overcome as the user becomes more familiar with the process. Some of these difficulties can be cited briefly.

The stoppage of oil supply lines from the pump can be cleared up in

very short time by disconnecting the intake from the tank and circulating common kerosene oil through the lines for a short time and draining out. Some users even go to the extent of using a small amount of kerosene with the fuel oil, thus preventing a complete shutdown while the deposit is being removed.

Water accumulation in fuel oil storage tanks, coming from tank cars, will occasionally cause considerable trouble especially when a rotary pump is used. If the water level rises high enough it will be drawn through the pump where a water-oil emulsion is formed, which is almost impossible to burn. It spits and fries in the kiln fire-box, sometimes refusing to burn, and results in loss of time and temperature. When such a condition is encountered the oil should be pre-heated to about 220°F if its flash point will permit and the moisture driven off through a large temporary ventilator. However, such a circumstance need never arise if an occasional inspection is made of the settlings leaving the drain cocks.

Exceedingly erratic results are occasionally obtained when an inexperienced fireman first uses oil. The great tendency is to produce reducing conditions within the kiln, resulting in bloated pyrometric cones, black caking and a deposition of carbon in the kiln mouth, which must be continually broken off to prevent flashing back. The carbon deposit builds horizontally from the back of the kiln mouth toward the burner in the form of a cylinder. The atomized fuel striking this is diverted toward the arch and kiln door, heating these red hot. With proper care in the regulation of the mixture of oil and air, and with adequate combustion space these conditions are minimized.

Radiation losses are very much greater when the kilns are fired under slight pressures. While this may seem to be a rather inefficient condition, the results seem to show that much better heat distribution is obtained. With an improvement in quality of kiln lining refractories backed up with insulating material, the radiation loss should be no greater than when the old style gas burners or coal were used.

A vital mistake is made by applying oil burners to kilns whose fire-boxes were originally intended for gas or coal without proper changes. The combustion space must necessarily be much larger when burning concentrated fuels and more space should be allowed for the heat to pass into the kiln over the bags and through the radial flues.

Oil-fired kilns of this type require more frequent attention from the fireman due to the intensity of the oil flame, and its effect on the deformation of the pyrometric cones.

A STUDY OF THE SLAG TEST

By R. M. HOWE

ABSTRACT

Several methods of making slag tests are discussed. A large amount of experimental data pertaining to the "penetration" test are presented. They show that there is no relationship between the results obtained in the plant and in the laboratory. A newer method of testing appears to give more satisfactory results. This is based upon the depression of the melting points of refractories by the addition of slags.

Introduction

By 1917 two important methods for studying the action of slag upon refractory materials had been developed in this country, one at the U. S. Bureau of Standards and the other at the laboratory of the Carnegie Steel Company. Since that time this action has been studied intermittently at the Mellon Institute of Industrial Research and the results have been summarized in the following paper.

The method employed at the U. S. Bureau of Standards was as follows:¹

Fire-clay boxes, whose inside dimensions were 9 inches in length, 8 inches in width, and 3 inches in depth, were molded from a finely ground refractory mixture and burned to cone 12. Each brick to be tested was placed on edge in the box and firmly packed with the finely ground slag on the two sides. In the first series of tests, slag prepared from the ash of the coal was used. In the later tests the brick were subjected to the action of a synthetic mixture having a composition approaching that of the slag.

Twelve of the boxes were placed in a down-draft kiln fired with natural gas. The temperature was increased to 1400°C, over a period of 36 hours. For this slag, reducing conditions were maintained in the kiln over the last 12 hours of the burning. . . . In order to observe the corrosive action and penetration of the slag, each box that contained brick was broken into two or three parts.

The advantages claimed for the method are:

1. A large portion of the brick is subjected to the action of the slag.
2. A large quantity of slag is used, thus preventing appreciable changes in its chemical and physical properties as action progresses.
3. The time effect may be studied.

The main details of the method developed at the laboratory of the Carnegie Steel Company were as follows:²

1. Drill two standard sized cavities in each of three or more brick.
2. Select a suitable slag and grind to 40-mesh size.
3. Heat the test brick to 1350°C in not less than 5 hours, introduce 35 grams of slag to each cavity, and allow it to react at that temperature for 2 hours.
4. Saw the cooled brick so that each cavity is bisected and measure the area penetrated by the slag. This penetration is used as a means of expressing the relative resistance of each brick to the action of that particular slag.

¹ G. H. Brown, "A Method of Studying the Corrosive Action of Slag on Fire-brick." *Trans. Amer. Ceram. Soc.*, **18**, 277 (1916).

² *Proc. Amer. Soc. Testing Materials*, **17**, 669 (1917).

This was adopted as a tentative method by the American Society for Testing Materials in 1917. The writer then began a systematic study of the method from a laboratory standpoint and at a later date was able to compare test results with those obtained under service conditions. Seven samples of slag¹ and three brands of fire brick were used in making the first tests. The analyses of the slags are given in Table I.

TABLE I
ANALYSES AND MELTING POINTS OF SLAGS

	Blast furnace	Heating furnace	Basic open hearth	Acid open hearth	Coal ash	Zinc	Copper
Silica.....	37.72	34.16	18.42	46.48	54.86	34.30	28.20
Alumina.....	13.21	6.13	3.85	5.45	30.50	14.74	2.20
Iron Oxide.....	1.62	43.60	14.55	29.30	7.20	21.00	2.10
Lime.....	42.20	1.30	44.10	2.16	.00	2.33	2.51
Magnesia.....	2.35	.65	6.32	.00	2.01	7.07	2.14
Manganese.....	1.11	.55	5.09	9.08	.09	6.77	.00
Sulphur	1.20	.27	.42	.38	.38	5.88	.14
Phosphorus.....	.00	.02	.58	.00	.01	.02	.24
Copper.....	.00	.00	.00	.00	.00	1.28	58.21
Zinc.....	.00	.00	.00	.00	.00	8.20	.00
Melting Point—°C.....	1220	1050	1275	1400	1130	1025	1020

The fire brick, A, B, and C, were typical first-quality products of the New Jersey, Kentucky and Pennsylvania districts.

Influence of Time

Among the first tests were those in which samples of fire brick C were subjected to the action of 35 grams of slag at 1350°C for 2-, 4-, and 6-hour periods. The penetrations were .64, .68, and .64 inches, respectively. It was evident, therefore, that the penetrations observed in these tests were practically complete in less than two hours. In this respect the results differed from those obtained in service, where the action of slag is progressive and very largely dependent upon the time factor.

Influence of Quantity

In the next tests the samples were subjected to the action of 35 and 105 grams of slag for 2 hours at 1350°C. The penetrations were .64 and .76 inches, respectively. Thus, an increase of 200% in the severity of the test resulted in 19% greater penetration.

Influence of Time and Quantity

Further tests were made in which both the time of reaction and the quantity of slag were increased. The results are given in Table II.

¹ By courtesy of J. S. Unger, Central Research Bureau, Carnegie Steel Company, Pittsburgh, Pa.

TABLE II
INFLUENCE OF TIME AND QUANTITY OF SLAG UPON PENETRATION

	2 hours	4 hours
35 grams	.64 in.	.68 in.
105 grams	.76 in.	.72 in.

In this case the severity of the test was increased from 100 to 500%, yet the observed penetration showed a maximum increase of only 19%. As a matter of fact this variation in the results is within the possible experimental error.

Influence of Furnace Atmosphere

It is a well-known fact that the melting points of slags show considerable variation, depending to a very large extent upon the furnace atmosphere in which they are heated. One coal ash was reported, for example, as melting at 1086°–1119°C under reducing conditions and at 1279°–1305°C under oxidizing conditions. A slag of this nature might give far different results in the slag test if the furnace atmosphere varied, for the activity of a slag at a given temperature would be affected by the same factors that influence its melting point.

Several tests were made in which a highly oxidizing or highly reducing atmosphere was maintained in the furnace. They were conducted for two hours at each of four temperatures. Copper and heating furnace slags were used because of the fact that they contain 58.2 and 43.6% of copper and iron, respectively. The copper slag melted at 1020°–1090°C according to the furnace atmosphere, while the heating furnace slag melted at 1050°–1350°C. The penetrations obtained under the various conditions are recorded in Tables III and IV.

TABLE III
SLAG PENETRATIONS OF BRICK A UNDER DIFFERENT FURNACE CONDITIONS

COPPER SLAG			HEATING FURNACE SLAG		
Temperature	Oxidizing	Reducing	Temperature	Oxidizing	Reducing
1150°C	.46 in.	...	1150°C	.04 in.	.48 in.
1250°C	.65 in.	.17 in.	1250°C	.09 in.	...
1350°C	.35 in.	.30 in.	1350°C	.15 in.	...
1450°C	.39 in.	.26 in.	1450°C	.34 in.	.90 in.

TABLE IV
SLAG PENETRATION OF BRICK C UNDER DIFFERENT FURNACE CONDITIONS

COPPER SLAG			HEATING FURNACE SLAG		
Temperature	Oxidizing	Reducing	Temperature	Oxidizing	Reducing
1150°C	.52 in.	...	1150°C	.07 in.	.68 in.
1250°C	.62 in.	.45 in.	1250°C	.10 in.	...
1350°C	.83 in.	.45 in.	1350°C	.24 in.	...
1450°C	.46 in.	.30 in.	1450°C	.78 in.	.94 in.

Thus, it was demonstrated that the results of the slag test depend to a very great extent upon the atmosphere of the furnace. In the case of the

copper slag, metallic copper actually separated out under reducing conditions and in that way lowered the active constituent of the slag. The heating furnace slag was more active under reducing conditions because of the greater activity of the ferrous compounds as compared with those containing ferric iron. The furnace atmosphere should, therefore, be carefully controlled if comparative results are to be obtained with slags of this type.

Effect of Furnace Temperature

The effect of varying the furnace temperature was next studied for it seemed as if greater flexibility should be allowed in this feature of the test. Inasmuch as certain slags are heated to much higher temperatures than others in service, it would be logical to follow the same practice in making the tests. While 1350°C might be ideal for certain slags and furnaces, a higher or lower temperature would be more satisfactory for others.

Three brands of fire brick were subjected to the action of seven slags at 1150, 1250, 1350 and 1450°C. The slags were heated for two hours under oxidizing conditions. The results are given in Tables V, VI, and VII.

TABLE V
PENETRATION OF DIFFERENT SLAGS ON FIRE BRICK A

Slag	Blast furnace	Heating furnace	Basic open hearth	Acid open hearth	Coal ash	Zinc	Copper
1150°C.....	...	.04	...	...	.01	.03	.46
1250°C.....	.03	.09	...	...	.01	.13	.65
1350°C.....	.08	.15	.58	...	.03	.28	.35
1450°C.....	.14	.34	.73	.24	.02	.19	.39
Melting pt. of slag.....	1220°C	1050°C	1275°C	1400°C	1130°C	1025°C	1020°C

TABLE VI
PENETRATION OF DIFFERENT SLAGS ON FIRE BRICK B

Slag	Blast furnace	Heating furnace	Basic open hearth	Acid open hearth	Coal ash	Zinc	Copper
1150°C.....	...	.02	...	...	.01	.04	.36
1250°C.....	.00	.05	...	...	.02	.16	.57
1350°C.....	.11	.11	.29	...	.03	.29	.39
1450°C.....	.17	.79	.33	.33	.02	.32	.34
Melting pt. of slag.....	1220°C	1050°C	1275°C	1400°C	1130°C	1025°C	1020°C

TABLE VII
PENETRATION OF DIFFERENT SLAGS ON FIRE BRICK C

Slag	Blast furnace	Heating furnace	Basic open hearth	Acid open hearth	Coal ash	Zinc	Copper
1150°C.....	...	.07	...	...	.01	.05	.52
1250°C.....	.07	.10	...	...	.02	.24	.62
1350°C.....	.12	.24	.44	...	.01	.33	.83
1450°C.....	.17	.78	.55	.57	.02	.43	.46
Melting pt. of slag.....	1220°C	1050°C	1275°C	1400°C	1130°C	1025°C	1020°C

These data show that the penetration at different temperatures are not in the same ratio. Consequently, the results at any single temperature cannot be accepted as being typical. In order to secure a comparison between different fire brick it is at least necessary, therefore, to test them at a temperature approximating that of the industrial furnace in which the slags are melted.

In making this study a far more serious criticism of the test was discovered, however. It became evident that no distinction was made between mechanical penetration and chemical action when the results were reported in terms of penetration. The lack of this distinction and its practical importance was particularly noticeable in the results obtained with the copper slag. These have been recapitulated in Table VIII.

TABLE VIII
PENETRATIONS OF COPPER SLAG AT FOUR TEMPERATURES

Brick	1150°C	1250°C	1350°C	1450°C
A.....	.46 in.	.65 in.	.35 in.	.39 in.
B.....	.36 in.	.57 in.	.39 in.	.34 in.
C.....	.52 in.	.62 in.	.83 in.	.46 in.

At 1150° and 1250°C the results indicate the extent to which the slag had seeped into the brick, filling the pore spaces, but not taking the clay into solution. The action was practically the same as when water penetrates a concrete pillar, there being no loss in mechanical strength due to this penetration. At 1450°C the action was entirely different for the slag completely dissolved the brick as it penetrated, decreasing its value proportionately. These facts are not brought out in Table VIII, and one might infer that the behavior of brick C was better at 1450°C than at 1250°C. As a matter of fact, the penetration of .62 in. at 1250°C was not in the least serious, whereas the penetration of .46 in. at 1450°C represented failure.

A similar condition can arise very easily when fire brick of different types are being tested at any one temperature. Those which are open and porous will always show a large penetration, although they may be unaffected by the solvent action of the slag. On the other hand, very dense brick may show a low penetration, although they are seriously attacked.

After having conducted this extensive laboratory investigation of the slag test, there was considerable doubt in the writer's mind as to its practical value. Nevertheless, two attempts were made to reconcile the results obtained with those obtained in service.

The first attempt was made in a checker-work where the brick were rapidly cut away by the corrosive action of slag. Three brands were selected for a competitive test and the results follow:

Type	Grind	Process	Fusion point	Slag penetration	Service
1.....	Fine	Steam-press	Cone 31 ¹ / ₂	.29 in.	Fair
2.....	Medium	Hand	Cone 32 ¹ / ₂	.52 in.	Good
3.....	Medium	Steam-press	Cone 32 ¹ / ₂	.00 in.	Good

It can be seen that there is no relationship between the results of the slag test and the service obtained, although the brick failed in each case because of slag action. The writer concluded that inasmuch as the same raw material was used in making bricks 2 and 3, it was more resistant to the action of slag than that which was used in those of type 1. Being resistant to this action, the question of density was of little importance in service for the steam-pressed (3) and hand-made brick (2) gave practically the same results. On the other hand, the denser steam-pressed product (3) gave far better results in the laboratory.

At a later date two brands of fire brick of the following characteristics were subjected to a competitive test in a cupola:

	A	B
Burn	Hard	Medium hard
Grind	Fine	Coarse
Fusion Point	Cone 29 to 31	Cone 31
Penetration of Slag in Laboratory Test	3.58 sq. in.	5.35 sq. in.
Chemical Analysis		
Silica	52.70	57.84
Alumina	38.17	34.14
Ferric Oxide	6.30	2.75
Lime	.18	.30
Magnesia	.13	.58
Alkalies	.93	1.59
Titania	1.89	2.75
Total	100.30	99.95

Standard 4" x 6" blocks were laid up in each half of a Whiting cupola so that they received identical treatment. They were first dipped in a thin fire-clay slip, were then hammered into place, and finally covered with additional slip.

The furnace was running on new pig and clean scrap, using Syracuse limestone as a flux. Sixty-five to sixty-eight ton heats were taken off in three hours. After 48 hours 4 inches of the "A" blocks had been eaten away, while only 1 inch of the "B" blocks had been affected.

Three striking contrasts were noted between the practical and test results:

1. In practice, the slag never penetrated more than .25 of an inch while in the test the depth of penetration was .5, 2.0, 2.0 and 3.5 inches.
2. In practice, the penetration was uniform; in the test it was not.
3. In practice, the "B" blocks gave four times the service; in the test, the "A" blocks were better by 50 per cent (ratio = 3.58 : 5.35).

These results convinced the writer that there was no relationship between the results of this slag test and the action of slag in service.

Another method, based on entirely different principles, had been advocated for some time, but had never been investigated in this laboratory. The lack of investigation was due to unfavorable reports received in 1917. Favorable reports were received later and it was decided to apply the method in testing the cupola blocks previously described.¹

Samples of each block were ground to pass 60-mesh and were then mixed with different percentages of slag. These mixtures were made into cones and their fusion points determined. In making these determinations it was assumed that all fire brick are ultimately penetrated by slag. This being the case mixtures of fire brick and slag are formed on the inside of the furnace. If these mixtures are of high melting point they will be less affected at a given temperature than those of lower refractoriness. Consequently, the relative fusion points of several brick slag mixtures should indicate the resistance of those brick to the action of that slag.

The fusion points of the A and B brick and slag mixtures are given in Table IX.

TABLE IX

Per cent slag	Fusion points of A and B brick with Slag No. 1		Fusion points of A and B brick with Slag No. 2	
	A	B	A	B
4	20-26	27-28	17-18	26-27
8	19	20-26	16-17	20
12	15-16	18	14	14-15

It is evident from these results that the linings of type A were less resistant than those of type B to the chemical action of the slags. On the other hand, those of type A were more resistant to penetration, as was shown by the slag tests. In view of the service obtained from the two blocks in this particular case one would conclude that resistance to chemical action was of more importance than resistance to penetration. At least the test which is based upon the solvent action of the slag gave results in agreement with those obtained in service, while the test which measured penetration did not. Since the claims made for the practical value of the fusion point method of making slag tests were justified in this case, plans were made for further investigation, the results of which will be reported at a later date.

Summary

Two distinct types of slag tests have been studied in this laboratory. In one case the penetration of the slag is measured by means of a planimeter; in the other its solvent action is determined by studying its effect upon the fusion points of fire brick.

¹ H. D. Fischer, "Looking for a Brick," *Combustion*, February, 1919.

Eight points were developed in the study of the penetration test. The results of the test are not influenced to an appreciable extent by increasing the time of the test or the amount of slag. They are affected by the furnace atmosphere. Generally speaking penetration increases with an increase in temperature, although the increase with different slags and brick are not relatively the same. The results are controlled to a very large extent by the density of the brick, being low with the steam-pressed product and high with the hand-made. The results also appear to be lower with the finer grinds. It was impossible to discover any relationship between the laboratory and practical results. A very serious weakness of the test was found in the method of reporting, it being impossible to describe the action of the slag by simply recording the penetration.

The other test was not studied in great detail, but the results to date are very encouraging.

Discussion

In most cases the surface of the brickwork in contact with the slag is much hotter than the inner portions. Consequently, as the slag penetrates a short distance it becomes more viscous at the lower temperature of the interior of the brick and finally solidifies. Further penetration is impossible until the temperature equilibrium is disturbed. This is not destroyed until the diameter of the hearth is increased by the solvent action of the slag upon the refractory brick.

Slag action is, therefore, divided into two parts—penetration and solution. Penetration, however, is not necessarily important, for the penetrating slag may have no solvent effect whatsoever upon the brickwork. In any event, the action of the penetrating slag will always be less severe than that of the hotter, more concentrated slag at the surface. Furthermore, penetration will always cease as the cooler portions of the brick work are reached.

On the other hand, the solvent action of the slag upon the fire brick is extremely important, for as it progresses new portions are exposed and complete destruction finally results. It is dependent only to a very slight extent upon penetration, for, as has already been stated, the greatest solvent takes place at the hotter surface.

It is not surprising, therefore, that a slag "penetration" test is of slight practical value, for its results may be obscured by a high or low resistance to solvent action. On the other hand, a test designed to show resistance to chemical action should give information of practical value. Present information indicates that the fusion point method measures solvent action and, therefore, supplies an urgent need. This method is now being studied in detail and the results will be reported at an early date.

Official Personnel of Divisions, 1922-23

	Art	Enamel	Glass	H. Clay Prod.	Refractories	Terra Cotta	White Wares
Chairman	F. H. Rhead	B. T. Sweely	J. C. Hostetter	C. F. Tefft	J. Spotts Mc-Dowell	A. F. Hottinger	F. K. Pence
Vice-Chairman	H. S. Kirk	R. R. Danielson	A. R. Payne	D. F. Stevens	E. H. Van Schoick	R. L. Clare	C. C. Treischel
Secretary	M. C. Farren	R. R. Danielson	A. E. Williams	M. B. Greenough	Fred A. Harvey	E. C. Hill	F. K. Pence
Committee on Research	F. H. Rhead		E. C. Sullivan	O. W. Renkert	R. M. Howe	Major Gates	L. H. Bown
			E. W. Washburn	R. T. Stull	E. N. McGee		F. S. Hunt
			R. B. Sosman	G. W. Shoemaker	G. F. Bissell		V. S. Schory
				Warren Griffis	W. E. Dornbach		Ira E. Sproat
				Paul E. Cox	F. A. Harvey		O. O. Bowman, 2nd
				R. K. Hursh	S. M. Kier		August Staudt
			*				Leslie Brown
							C. C. Treischel
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No. 3

PRELIMINARY REPORT¹ ON THE RESIDUAL KAOLIN AND FELDSPAR IN THE PACIFIC NORTHWEST

BY HEWITT WILSON, A. LEE BENNETT AND FRED T. HEATH

ABSTRACT

Large quantities of residual crystalline kaolin are found in the Inland Empire district of eastern Washington and northwestern Idaho. Preliminary investigation has shown that the properties of these clays, when properly selected and purified, will compare favorably with those of the English china clay upon which the eastern potters and paper manufacturers are largely dependent. With the low cost of the English clay laid down on the Atlantic Coast, it is not believed that the Pacific Northwest clay will be used as a substitute for the English in the eastern markets, but the domestic source will provide the bulk of the raw material for the future whiteware industry in the Pacific Northwest. Commercial quantities of feldspar, quartz, and fire clay are also found in the Pacific Northwest.

The work described here was conducted at Seattle under a coöperative arrangement between the College of Mines, University of Washington, and the Northwest Experiment Station of the U. S. Bureau of Mines.

The Importance of Residual Kaolins in the Manufacture of Porcelain and Whiteware Bodies

Messrs. Schurecht,² and Jones³ have noted the importance of devel-

¹ Published by permission of the Director of the U. S. Bureau of Mines, 1922.

² H. G. Schurecht, "The Microscopic Examination of the Mineral Constituents of Some American Clays," *Jour. Amer. Ceram. Soc.*, **5**, 3-24 (1922).

³ C. H. Jones, "Pottery Manufacture in the East Liverpool District," *Chem. and Met. Eng.*, **26**, 350 (1922).

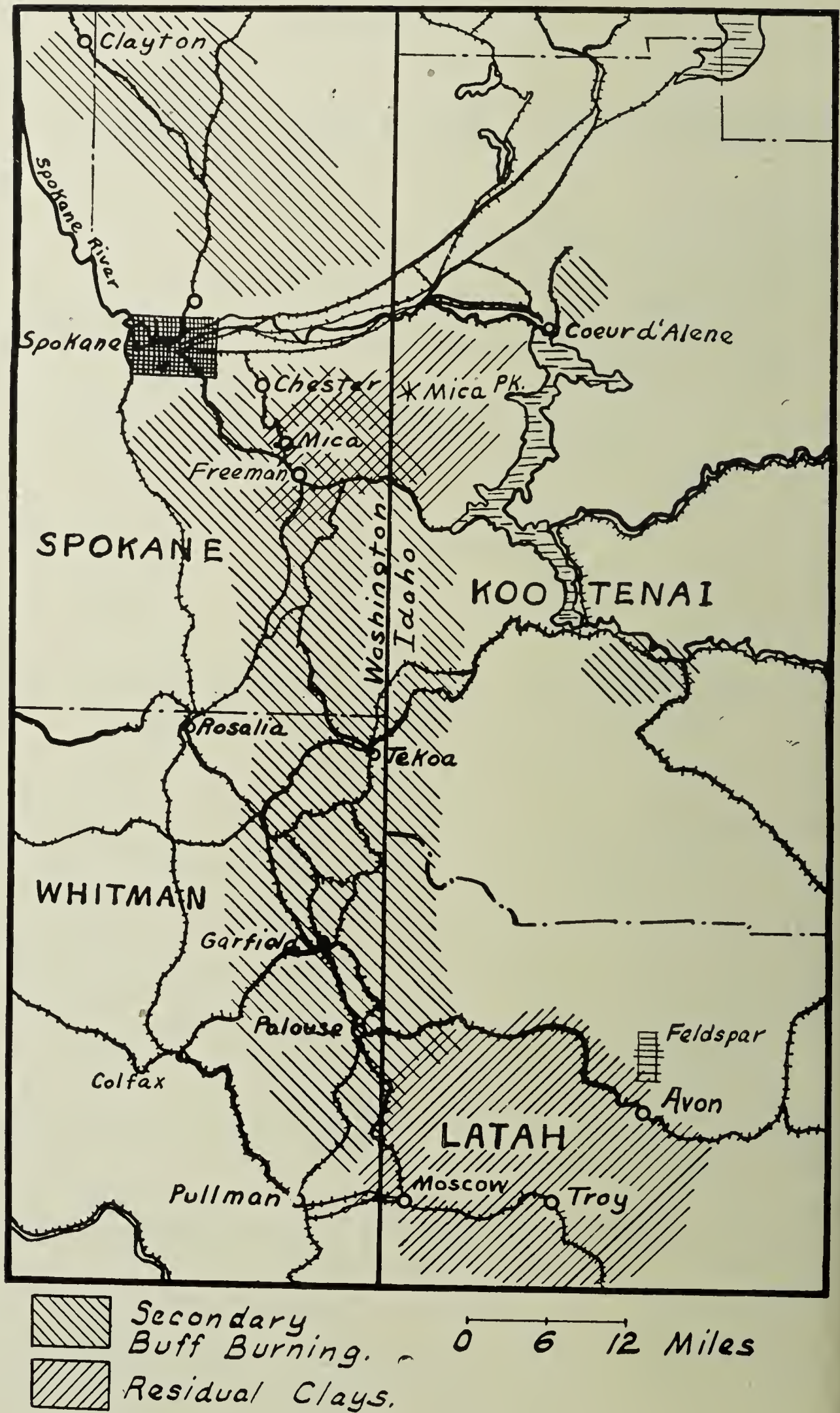


FIG. 1.—Map of the Inland Empire of eastern Washington and northwestern Idaho

oping in the United States new deposits of the crystalline type of kaolin for the whiteware industry. English china clay from Cornwall has the widest use and best reputation among the potters of the East and hence is held as a standard for all American china clays. Two general classes of kaolins are found in the eastern part of the United States. The first, represented by small deposits in North Carolina, has a geological history similar to that of the English, and is composed in large part of the platy crystalline kaolinite,¹ but the particles are coarser, the plasticity weaker, and the available quantity limited. Small deposits of residual kaolins are likewise found in Pennsylvania and Delaware.

The transported white clays of Georgia, South Carolina, Florida, and Pennsylvania consist largely of "colloidal" kaolin particles and are thus finer grained, more plastic, and stronger, but have a greater shrinkage and entirely different working properties from the English china clay. Experiments conducted under the stress of the war shortage showed that mixtures of the two types of American clays will give bodies which duplicate the English china clay very closely, but the unfortunate part of the situation is that while the "colloidal" kaolins can be found in great abundance, the residual kaolins of North Carolina, Pennsylvania, and Delaware are limited in amount. Thus very little hope is offered toward the complete independence of the American potter and paper manufacturer from the English or some other foreign china clay.

Shortage in the eastern part of the country, combined with the need of whiteware industry in the Pacific Northwest, has led to the investigation of the deposits of residual kaolin in the celebrated Inland Empire region of eastern Washington and northwestern Idaho. These clays have already been used for a number of years by four companies for making a "white" grade of fire brick.

General Geology of Central Eastern Washington and Northwestern Idaho²

The rocks of Spokane, southeastern Stevens, and Whitman Counties in Washington, and Latah County, Idaho, consist principally of granite, quartzite, and basalt. The quartzite, which is the oldest and is probably pre-Cambrian, has altered in places to quartz schist and gneiss. The granite occurs as a large intrusion into the quartzite and quartz schists

¹ G. Hickling, "China Clay, Its Nature and Origin," *Trans. Inst. Min. Eng.*, 36, 1908-1909. R. E. Somers, "Microscopic Examination of Clays," *Jour. Wash. Acad. Sci.*, 9, 113 (1919). H. G. Schurecht, *loc. cit.*

² E. K. Soper, "Fire Clays of Northern Idaho," *Jour. Amer. Ceram. Soc.*, 1, 94 (1918). Sheldon L. Glover, *Wash. Geol. Surv.* Unpublished notes. Frank H. Skeels and Hewitt Wilson, "A Preliminary Report on the Clays of Idaho," Bureau of Mines and Geology, State of Idaho, *Bull.* 2, 1920.

and is probably of Cretaceous Age. This enormous granite batholith is now exposed over many square miles in the Rocky Mountain region to the east and southeast in Idaho. In the white clay district of lower elevation the quartzite and associated pre-Cambrian sediments have mostly been eroded or buried.

The basalt is of Miocene Age and occurs as a series of flows which originally covered a large area in southeastern Washington (approximately bounded by the Columbia and Spokane Rivers on the west and north respectively), the Snake River plains in Idaho, and a large part of eastern Oregon. Erosion has removed or softened a large part of the thinner capping which occurs at the higher elevations (2,200 to 2,500 ft.) and has exposed the weathered granite masses beneath. Wood fragments occurring between the residual clays and the overlying basaltic material indicate an old weathered surface which antedates the volcanic activity. In many places the basalt capping has prevented the erosion of the soft clays beneath, hence the age of the residual clay may vary from pre-Miocene through Miocene to post-Miocene. The softening of the basalt capping to form red and brown-burning clays is often accompanied by the staining of the underlying white clays by percolating waters, and where the two have been removed and deposited in other places together, dark burning, semi-refractory clays will be found.

The granite from which the residual white clays were formed is rich in feldspar and low in hornblende, biotite, and the other ferro-magnesian minerals. In a small belt, about two miles wide and several miles long located from three to six miles north of Avon, Idaho, well-developed pegmatite is found, in which it is possible to mine white mica, feldspar, and quartz, in commercial quantities.¹ Mica mines have been operated there intermittently since 1888, and the feldspar and quartz discarded on the spoil dumps.

Because of the great age of these granites and their long exposure to weathering agencies with unfavorable conditions for the removal of the softened products, it is believed that the residual beds will produce an enormous tonnage of white-burning clay. The deposits which have been opened at the present time for fire clay give indications of very large underlying quantities.

Description of Residual Clay Openings

Freeman, Washington, Pit (Fig. 2).—The residual clay is taken from a pit just north of the Freeman Station on the Spokane and Inland Empire Railway, shipped to Clayton, mixed with a more plastic clay, and made into fire brick. The pit measures about 150 feet in diameter and extends

¹ D. B. Sterrett, "Mica in Latah County, Idaho." U. S. Geol. Surv., *Bull.* 530 "Contributions to Economic Geology," [1], 377-83, 1911.



FIG. 2.—Residual kaolin pit at Freeman, Washington, property of the Washington Brick, Lime and Sewer Pipe Co.

back into one of the hills forming the shoulders of Mica Peak. The overburden varies from 2 to 10 feet and the working face, more than 30 feet high, shows no indications of the hard, unweathered granite floor. Large masses of the kaolin, quartz, and mica mixture still retain the original graphic granite structure.

Joel, Idaho, Fire Clay Pit¹ (Fig. 3).—This pit is three to four miles southeast of Moscow and is reached by a side road from the main highway leading to Troy. It lies at an elevation of 50 to 60 feet above the highway in a hillside and has a 30-foot vertical working face, with only two feet of overburden, the remainder being a mixture of quartz, clay and mica. Partial sorting of the clay from quartz by movements

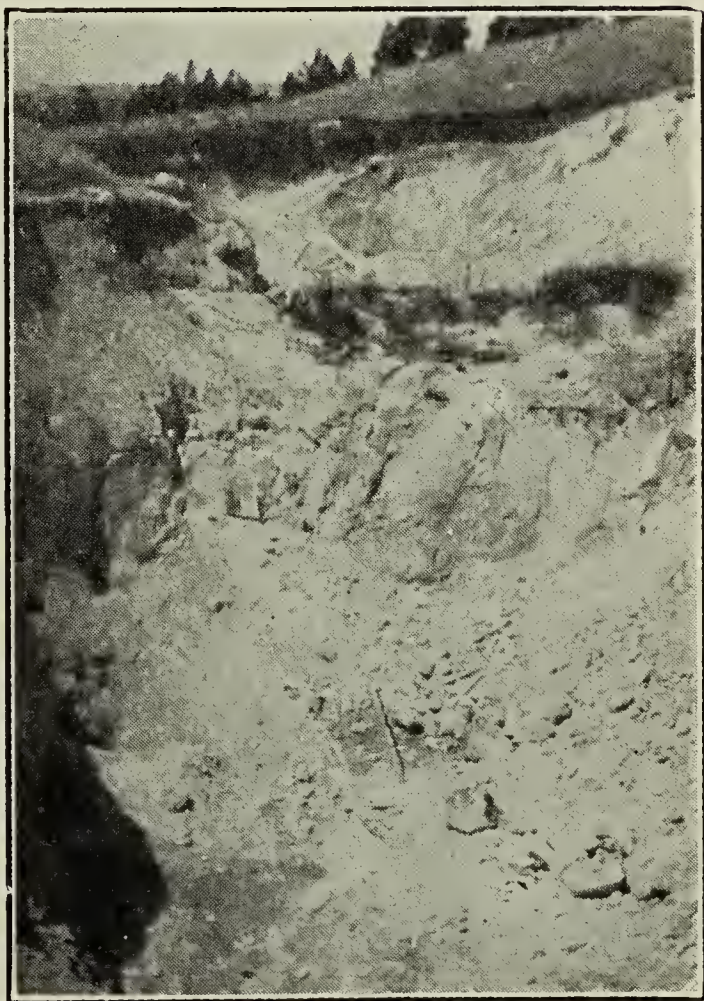


FIG. 3.—Residual kaolin pit at Joel, Idaho. The clay is used for fire brick by the Moscow Fire Brick Co.

¹ Private communication from E. F. Goodner, Washington Brick, Lime and Sewer Pipe Co., Spokane, Wash., and Dean F. A. Thomson, State Bureau of Mines and Geology, University of Idaho, Moscow, Idaho.

that have taken place within the deposit permit the easy elimination of masses of very sandy material. The mined product is a high-grade plastic material used at Moscow by the Moscow Fire Brick Company on the auger machine without other clays. An immense deposit is indicated by this exposure.

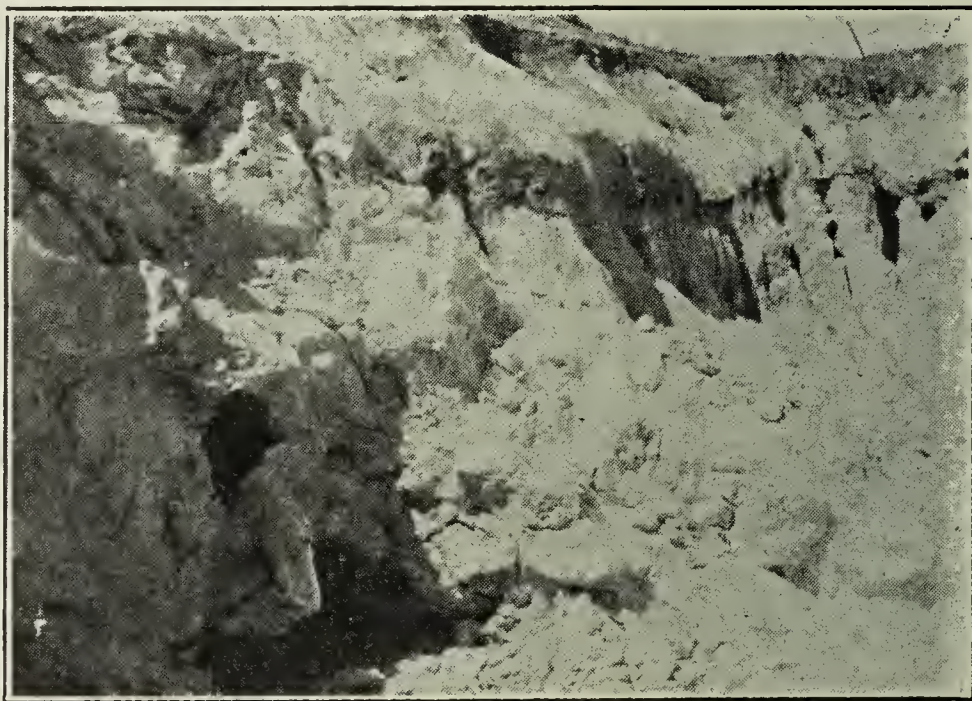


FIG. 4.—The Johansen fire clay pit. This residual kaolin is used for fire brick by the Idaho Fire Brick Company at Troy, Idaho.



FIG. 5.—The Lindeman fire clay pit. This residual kaolin is used by the Idaho Fire Brick Company for fire brick at Troy, Idaho.

Johansen Pit¹ (Fig. 4.)—The pit is located about five miles northeast of Troy, Idaho, one-fourth mile from the highway to Deary. A 15-foot

¹ Private communication.

exposure of very clean kaolin with only a small percentage of coarse quartz is found here. The clay is hauled by truck to Troy for fire brick manufacture at the Idaho Fire Brick Company's plant.

Lindeman Pit¹ (Fig. 5.)—Another excellent deposit of similar material is found one mile uphill from the Johansen pit. It likewise is hauled by truck to Troy for making fire brick.

Exposure One Mile North of Mica, Washington (Fig. 6.)—Similar white and gray material is exposed in a railroad cut about one mile north of Mica, Washington. A 40-foot face, deeply cut by erosion, lies within a few feet of the railway track and undoubtedly will prove valuable.

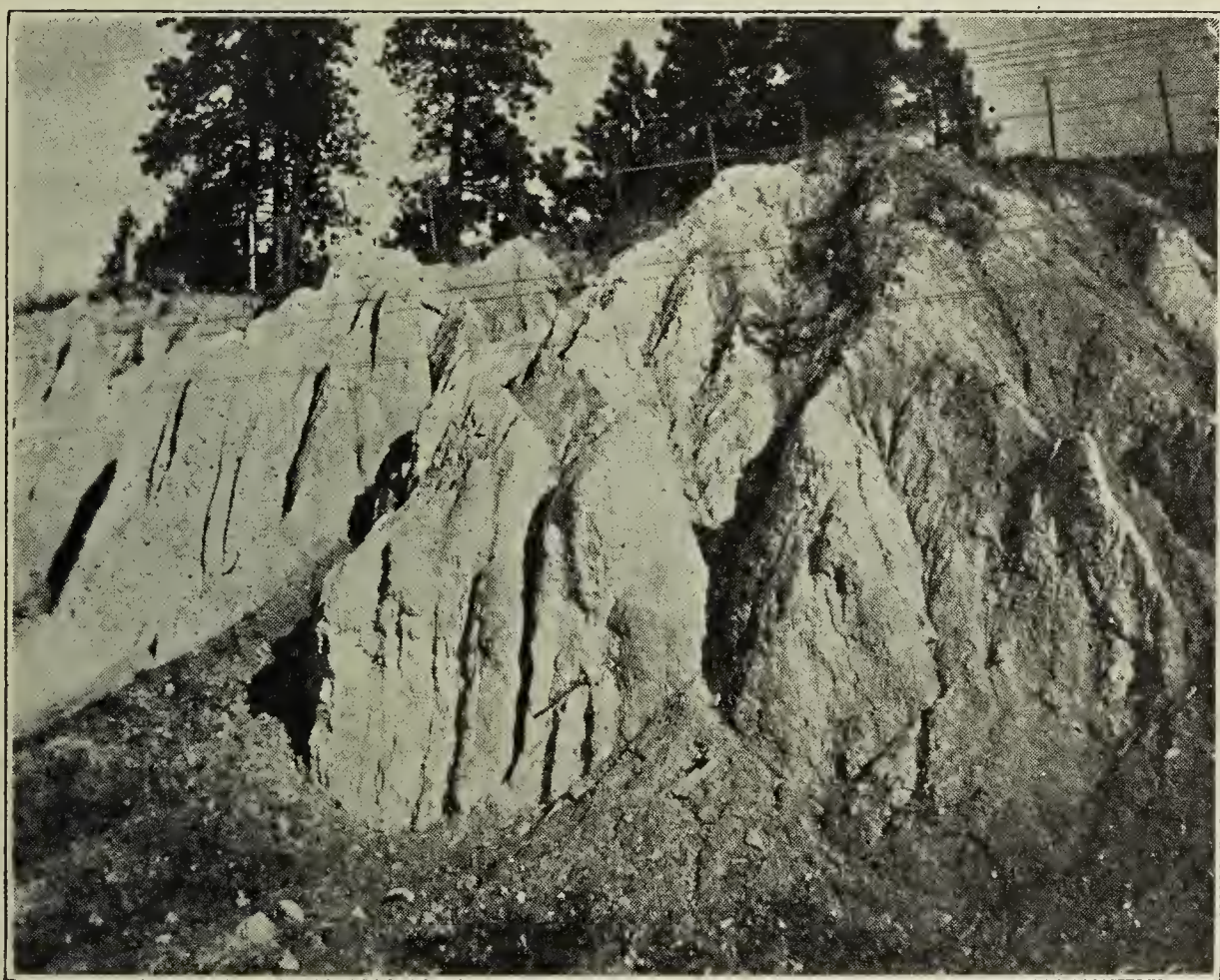


FIG. 6.—Unused deposit of residual kaolin in railroad cut one mile north of Mica, Washington.

American Fire Brick Company's Fire Clay Pit (Fig. 7.)—The north fire clay pit shows light-burning clay which has been concentrated either by colluvial action or by settling and movements within the bed. The pit measures about 300 feet in length and has a working face at the end, 5 feet wide and about 12 feet high. A much greater amount would be available if the workings were carried to more depth, for as far as known the granite basement has never been touched in this vicinity. The deposit is stripped and the plastic clay blasted out of the bed and hauled directly to the plant for a white-burning grade of fire brick.

¹ *Loc. cit.*

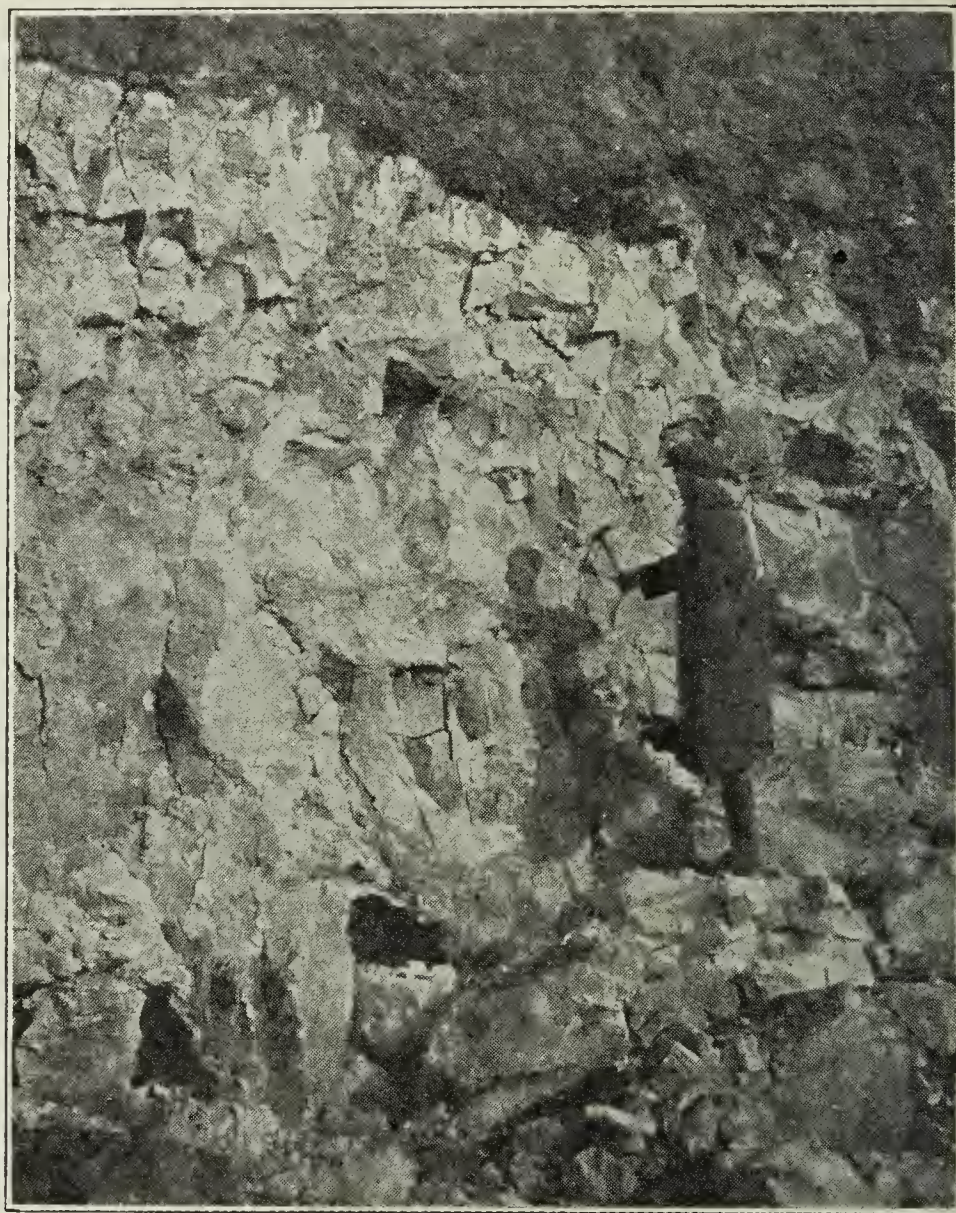


FIG. 7.—American Fire Brick Company's North or Fire Clay pit face of white-burning clay.

Feldspar and Mica Deposits

D. B. Sterrett¹ gives the following description:

The deposits lie in a north-south belt about two miles wide and several miles long. The mines and prospects examined are in T. 41 N., R. 2 W., from three to six miles north of Avon. They lie at elevations of 3,400 to 4,700 feet above sea level along the top and to the west of a high mountain ridge extending south from the Thatuna Hills.

The mica deposits occur in an area of highly schistose metamorphic rocks of pre-Cambrian Age. Muscovite and biotite schists and gneiss in which quartz is generally a prominent constituent, are the principal rock types of the region. Locally certain bands of the gneiss have an abundant development of black tourmaline crystals, especially near large pegmatite bodies. The gneisses and schists of this region strike roughly north and south, and the dips range from 50° W. to vertical. Masses of pegmatite cut the gneiss and schist and are in many places entirely conformable with the schistosity and in others only in part or not at all. Some of the pegmatite bodies outcrop continuously for distances of several hundred yards, with few variations in thickness or direction. Others have smaller outcrops. A bulging or swelling of the peg

¹ D. B. Sterrett, *loc. cit.*

matite bodies into chimney-like deposits also occurs and gneisses and schists apparently contain more pegmatite in the valley to the west of the high mountain ridge than in the ridge itself.

The principal properties are the Muscovite claim of Alexander Munro about five miles north of Avon, in sec. 22; the Levi Anderson mine, about four miles north of Avon, in secs. 22 and 27; the Maybe mine of Alexander Munro about one mile southwest of the Muscovite claim in sec. 22; the Luella mine of the Western Mica Company about $1\frac{1}{2}$ miles southwest of the Muscovite in sec. 21; and the Last Chance mine of Mrs. May Jorgensen of Seattle.

Commercial bodies of feldspar were found in the Last Chance, Luella, and Muscovite mines.¹ At the Last Chance mine there are several large dumps of clean feldspar and some which contain about 50 per cent quartz. As far as can be judged, there is a large quantity of feldspar available. Transportation can be managed by means of a logging road which is under construction to within a mile of the mine. The Luella mine has two adits which cut large bands of clean feldspar in several places. The Muscovite mine shows the most extensive workings and the dumps indicate that large bodies of feldspar and mica have been opened. A bank of semi-kaolinized feldspar is exposed for at least 20 feet. Feldspar dikes 16 feet in width were found in tunnels No. 2 and No. 3 and could be removed with very little quartz and tourmaline. Complete descriptions of these mines in regard to the mica can be found in *Bull.* 530, U. S. Geological Survey.

Secondary Buff-burning Clays

The basalt flows blocked the natural drainage of the country and developed many lakes and ponds at the foot of the hills near the boundaries of the flows. In some of these were deposited the white kaolin-like clay material, although it often is contaminated with surface wash containing iron impurities. Thus numerous deposits of fine-grained soft, plastic clays were formed in well-stratified beds. Leaf fossils are often found on bedding planes, and limonite or bog iron ore in nodules or sheets is associated with practically all these light-colored clays.

We have here, then, on a smaller scale, a reproduction of the clay-forming conditions of the Appalachian highlands and surrounding territory. From the softened granitic deposits of which only a few remnants remain, such as the North Carolina and Pennsylvania residual kaolins, the kaolinic materials were removed and carried to the east and south-east into New Jersey, South Carolina, and Florida, to form the secondary fire clays and kaolins, and to the west into Kentucky and Tennessee to form the fine-grained and plastic ball clays.² The latter, having journeyed

¹ Private communication, *loc. cit.*

² R. A. Schroeder, "Ball Clays of West Tennessee," *The Resources of Tenn.*, 9, 93 (1919).

farther and having been mixed with more impurities and subjected to greater organic action, have a greater colloidal development and a fired color further removed from pure white.

In northwestern Idaho and eastern Washington, we have an even greater distribution of the residual masses of softened granite rock which have not been deeply cut by erosion, while the secondary, the finer grained the more contaminated, and more plastic clays, lie to the west at lower elevations. The basalt blockade produced a series of swamps and lakes of quiet water comparable to the northern part of the Embayment area in Tennessee, Kentucky, and Illinois near the close of the submersion period.



FIG. 8.—Conner secondary clay pit, east of Clayton, Wash. Clay is used for terra cotta and stoneware.

Conner Plastic Clay Pit. (Fig. 8.)—The S. M. Conner clay pit is in the NE. $\frac{1}{4}$, NE. $\frac{1}{4}$ sec. 4, T. 29 N., R. 42 E., about five miles from Clayton. The pit lies in an old flat lake country surrounding Clayton and Deer Park and but a short distance from the old granitic hills. It measures about 75 feet by 125 feet and has been excavated to a depth of about 15 feet. An overburden consisting of loam, water worn pebbles, and coarse yellow sand varies from 3 to 7 feet in thickness. Separating this probably glacial drift from the clay is a continuous layer of limonite averaging about four inches in thickness. The clay occurs as thick-bedded, horizontal

rata, light gray to nearly white in color, and extends to a depth of over 10 feet. At the present time the clay is used for the manufacture of terra cotta at Clayton and stoneware at Spokane.

Some of the other deposits of a secondary type are found at:

1. Clayton, Wash. Property of the Washington Brick, Lime and Sewer Pipe Company. Used for fire brick and face brick.
2. Abbott Pit. NW. $\frac{1}{4}$, sec. 32, T. 30 N., R. 42 E., about six miles north of Clayton, Wash. Used for terra cotta.
3. D. C. Neafus Pit. Three-quarter miles east of the Conner pit the SE. $\frac{1}{4}$, sec. 34, T. 30 N., R. 42 E.
4. Chester Pits. SE. $\frac{1}{4}$, sec. 35, T. 25 N., R. 44 E., about three miles from Chester, Wash. station on the O. W. R.R. and N. Co. Used for making terra cotta in western Washington.
5. Palouse, Wash. Old stoneware pottery about 1.5 miles south of Palouse. Many other pits and prospect holes are opened in Stevens, Spokane, and Whitman Counties.

Experimental Work on Whiteware Bodies

Samples of the commercially-mined fire clays were obtained through the courtesy of the Washington Brick, Lime and Sewer Pipe Company, the Moscow Fire Brick Company, and the Idaho Fire Brick Company, from the Freeman, Joel, and Johansen pits, respectively. These are designated in the following report as the Freeman, Moscow, and Troy clays, respectively.

Purification of the Kaolins.—In order to remove the coarse quartz, mica, feldspar, etc., the kaolins were blunged with water, screened through 200-mesh sieve, filter-pressed, and dried. This crude washing process did not remove the fine quartz and mica. Therefore, a further separation of the Troy clay was made by settling and decantation. The Moscow and Troy samples approached a pure white color when dry, but the Freeman gave a light-cream tone.

As a basis of comparison, a sample of the Roessler and Hasslacher imported English china clay (washed) was tested with these clays. The former has an international use for whiteware and glaze work.

Testing, Methods and Results.—Standard-size test pieces (AMERICAN CERAMIC SOCIETY) were made separately from each of the three washed kaolins and from English china clay. Whiteware body mixtures were prepared for each clay separately by blunging together 50% of the clay, 30% of eastern Canadian feldspar, and 20% of flint. The plastic and dry results of these tests are given in the tables on following page.

TABLE I

			Per cent water of plasticity	Per cent pore water	Per cent shrinkage water	Per cent linear shrinkage
	Sample		On basis of dry weight			On basis of plastic length
100% clay	A-A	Freeman kaolin	54.1	23.2	30.9	9.4
100% clay	B-B	Troy kaolin	40.5	20.6	19.9	7.6
100% clay	C-C	Moscow kaolin	35.7	19.4	16.3	5.9
100% clay	D-D	English china clay	41.2	27.6	13.6	5.5
Whiteware body	A	Freeman kaolin	33.1	19.1	14.1	6.4
Whiteware body	B	Troy kaolin	29.9	16.9	13.0	5.7
Whiteware body	C	Moscow kaolin	29.6	18.5	11.1	5.2
Whiteware body	D	English china clay	29.5	21.5	8.0	4.3

TABLE II

DRY TRANSVERSE STRENGTH

Sample	100 Per cent clay	Whiteware body
Freeman kaolin.....	477.1 lbs. per sq. in.	332.2 lbs. per sq. in.
Troy kaolin.....	451.8 lbs. per sq. in.	336.4 lbs. per sq. in.
Moscow kaolin.....	442.9 lbs. per sq. in.	252.5 lbs. per sq. in.
English china clay.....	112.8 lbs. per sq. in.	98.5 lbs. per sq. in.

For the sake of comparison we list the transverse strengths of several kaolins, tested by Bleininger and Howat.¹

TABLE III

Sample	100 Per cent clay	Clay with 50 per cent sand
Georgia kaolin (a).....	325/sq. in.	210/sq. in.
Georgia kaolin (b).....	269/sq. in.	182/sq. in.
Florida kaolin.....	239/sq. in.	122/sq. in.
North Carolina kaolin.....	166/sq. in.	82/sq. in.
Eng. china clay (M. G. R.).....	98/sq. in.	52/sq. in.
Eng. china clay (M. W. M.)	74/sq. in.	56/sq. in.

These results would indicate that the Pacific Northwest kaolins possess greater dry strength than the others. Riddle and McDanel² in a series of tests on a number of porcelain bodies, obtained moduli of rupture varying from 140 to 250 pounds per square inch for unaged bodies of similar composition to those described here. Commercial china bodies tested by them were found to have moduli of rupture varying from 170 to 220 pounds per square inch. All of these values are lower than the results obtained on the porcelain bodies containing Northwest kaolins.

It is evident that the Freeman clay is more plastic than the others. The English china clay has a higher porosity in the dry state and this lack

¹ A. V. Bleininger and W. L. Howat, "The Compression, Tensile and Transverse Strength of Some Clays in the Dried State," *Trans. Amer. Ceram. Soc.*, **16**, 278 (1914).

² F. H. Riddle and W. W. McDanel, "Some Types of Porcelain," *Jour. Amer. Ceram. Soc.*, **1**, 606-27 (1918).

compactness is also evident by the weaker dry strength. In regard to linear shrinkage, the Moscow kaolin compares most favorably with the English china clay sample. On the basis of the plastic length, the former possesses less than one per cent greater shrinkage in both the 100% clay body and the whiteware mixture.

Fired Properties.—The test pieces were heated in saggers in a gas-fired laboratory kiln to a series of temperatures corresponding to cones 5 to 14, and cooled with the kiln.

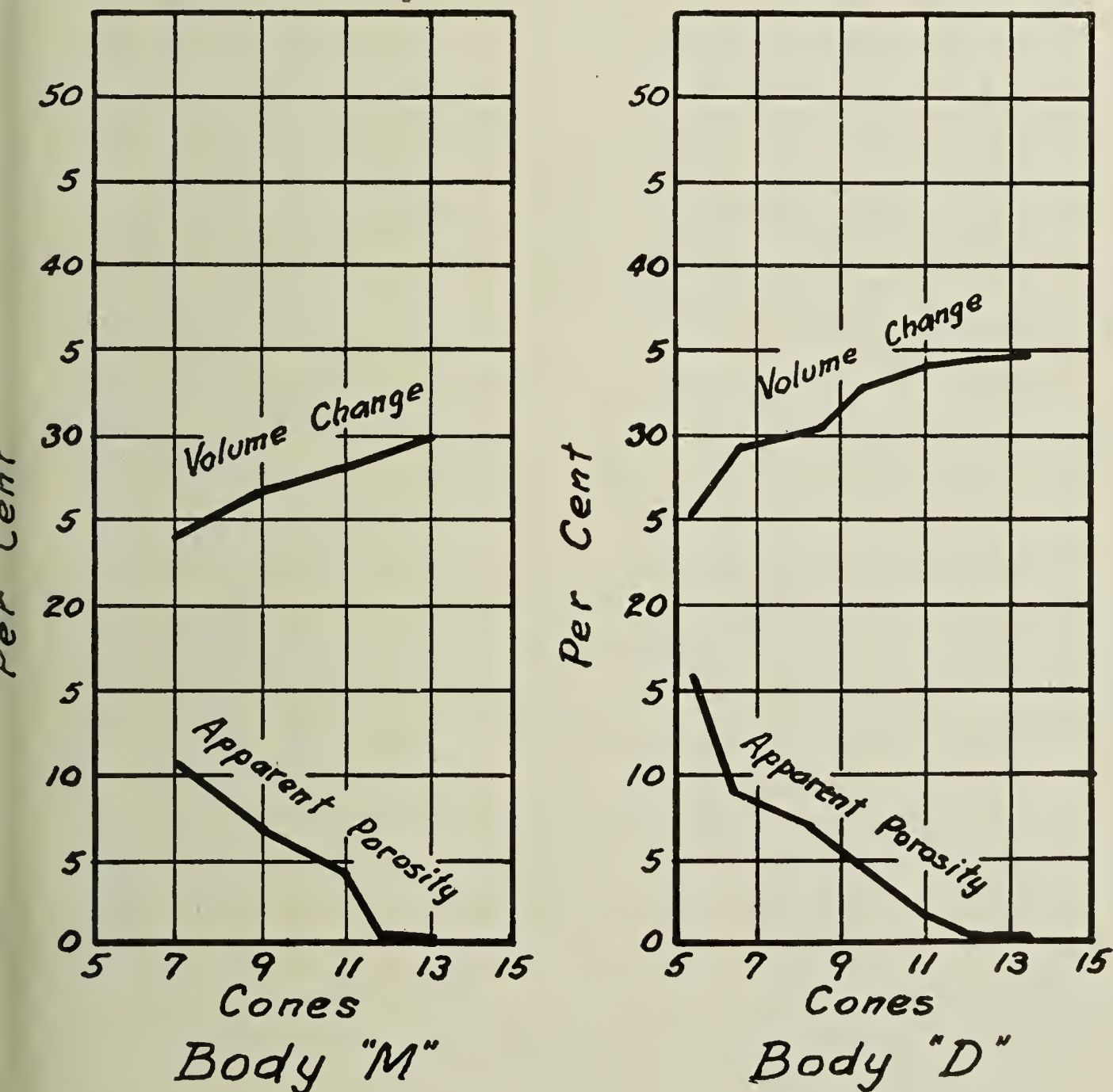


FIG. 9.

Body "A," containing Freeman clay, attained an apparent porosity of 2.0% and a volume change of 32.0% at about cone 13-14, which indicates that the density of commercial porcelains had not been obtained. Bodies "B" and "C," consisting of Troy and Moscow clays, respectively, possessed nearly identical properties, but likewise indicated that commercial porcelain density had not developed at cone 13-14. The volume change for both was 28% and the apparent porosity less than 1.0%.

Body "D" contained English china clay; the curves of its volume change and apparent porosity are shown in Fig. 9. This body is non-absorbent at cone 13.

The above-mentioned clay bodies from the Pacific Northwest possess strength, color, and density equal to many of the commercial whiteware bodies used for the cheaper but porous grades of ware. However, non-absorbent bodies were produced without raising the firing temperature by two methods, as follows:

1. An examination of the clays used in the above bodies "A," "B," and "C," shows that considerable free silica and mica remain even after washing through a 200-mesh sieve. An addition of 20% flint consequently raises the refractoriness of the mixture beyond the usual range of common porcelain bodies. This fact was proved by firing another series of bodies in which the flint content was eliminated and the feldspar content varied from 20% to 40%. The properties of the body with 30% feldspar compared very favorably with those of body "D" containing English china clay and flint.

2. The Troy clay was further washed very carefully by settling and siphoning methods to duplicate the purification of the English china clay. This eliminated the excess quartz and mica and gave a product which closely resembles the English clay in appearance.

Microscopic Examination of Washed Troy Kaolin.—A microscopic examination¹ was made of the washed Troy kaolin, and, as a basis for comparison, the washed English china clay sample also was examined. The results indicate that the Northwest kaolin also contains considerable crystalline kaolinite:

ESTIMATED PROPORTION OF MINERALS (Non-colloidal portion)				
Sample	Very abundant	Considerable	Small amount	Trace
Troy kaolin (washed)	platy crystalline kaolinite ²	micas ("sericitic")		zircon silica (as diatoms)
English china clay (washed)	platy crystalline kaolinite	micas (muscovite and sericite)	tourmaline	quartz (?)

Its mean refractive index was determined by oil immersion. A mixture of pure clove oil and α -bromonaphthalene was carefully prepared, which was just equal in refraction to the kaolinite plates. The refractive index of the mixture of oils was determined immediately, using an Abbé refractometer, the accuracy of which was previously checked by using known

¹ This work was done under the direction of Mr. Geo. E. Goodspeed, Professor of Geology, University of Washington, and Consulting Mineralogist, U. S. Bureau of Mines.

² The material recognized as "platy" kaolinite had low double refraction.

oils. The results thus obtained gave $n' = 1.553$ at 22°C . A comparison of the crystals with a pure sample of mono-brombenzene showed the kaolinite to be distinctly lower in refractive index than the mono-brombenzene, which was determined as $n' = 1.560$ at 25°C .

The refractive index of the crystalline kaolinite in the English china clay sample was also apparently lower than that of the mono-brombenzene (1.560), and the kaolinite in both Troy and English china clay samples was distinctly above 1.54 (Canada balsam).

Various authorities on this subject give different results for the refractive index of kaolinite:

Name of author	Date	Refractive index	Publication
1. H. G. Schurecht	1922	1.56-1.57	<i>Jour. Amer. Ceram. Soc.</i> , 5, 3 (1922).
2. W. E. Ford	1922	B = 1.482	Dana's "Textbook of Mineralogy," p. 578.
3. E. S. Larsen	1921	B = 1.565	"Microscopic Determination of Non-opaque Minerals," U. S. Geol. Surv., <i>Bull.</i> 679, p. 249.
4. L. M. Luquer	1913	$n' = 1.55$	"Minerals in Rock Sections," p. 115.
5. A. Johansen	1908	B = 1.54 (approx.)	"Rock-forming Minerals in Thin Section," p. 383.
6. N. H. & A. N.	1909	$n' = 1.563$	"Elements of Optical Mineralogy," p. 269.
7. J. P. Iddings	1906	$n' = 1.54$ (about)	"Rock Minerals," p. 454.

In the microscope slides, the Troy kaolin was very similar in appearance to the English china clay sample. A little iron-stained mica was found in both samples, the English china clay containing the larger amount.

The kaolinite crystals were apparently abundant in both samples, and about the same in size. Measurements showed the largest plates in both to be of approximately the same area as a 0.01 mm. square.

Whiteware Body Tests of Washed Troy Kaolin.—Body "M" contained 50% of this rewashed Troy clay, 30% eastern Canadian feldspar, and 20% flint. The firing curves of body "M" are also shown in Fig. 9 and a comparison can be made with body "D." A non-absorbent structure is produced at about the same cone with both bodies, but the fired volume change of the Troy clay body is less than that of the English. However, the dried volume change of the English body was less than that of the Troy, so that the total shrinkages are about equal. No cobalt was used in either body and the fired colors are very similar.

Idaho Feldspar.—A sample of feldspar from the Last Chance mine was obtained through the kindness of Dean F. A. Thomson of the University of Idaho. A chemical analysis gave the following:¹

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	Na ₂ O	K ₂ O	CaO	Total
66.80%	19.65%	0.85%	7.20%	3.00%	2.01%	99.51%

¹ Analytical Department of the Northwest Experiment Station, U. S. Bureau of Mines.

This result indicates that the feldspar is one of the high soda-lime types. The cone fusion is 6-7 with fast heating.

Microscopic Examination.—Crushed fragments of the feldspar showed an index of refraction almost equal to that of Canada balsam (1.540). It hence is classified as an "intermediate" feldspar, probably largely composed of oligoclase. Some orthoclase also was present but in small quantity. Throughout the sample shreds of micaceous material, probably sericite, were found. Some tourmaline (colorless variety) was present as inclusions in the feldspar, which likewise showed cloudiness from alteration to kaolin.

No appreciable difference was noted when this material was substituted for the eastern Canadian feldspar. More extensive testing will probably reveal the properties peculiar to this feldspar

Summary

1. Simple washing tests were made of three Pacific Northwest kaolins and a more refined elutriation was made of a fourth.
2. Fired whiteware and porcelain bodies of these clays show results comparable with bodies containing imported English china clay.
3. Although these clays are classed as residual and contain an abundance of crystalline kaolinite, their weathering has been complete enough to produce such a high degree of plasticity and bonding strength that it may not be necessary to use the usual off-colored ball clay content for the necessary plastic and dry strength. However, the substitution of an open-burning clay for a dense-burning clay ordinarily should be accompanied by an increase in the flux content or the firing temperature to produce the same degree of vitrification.
4. These preliminary results will be followed by more complete testing to secure data for a future whiteware industry in the Pacific Northwest.

DEPT. OF CERAMICS
COLLEGE OF MINES
UNIV. OF WASHINGTON
NORTHWEST EXPERIMENT STATION
U. S. BUREAU OF MINES

AN AUTOMATIC DIRECT READING LABORATORY SCALE FOR WEIGHING BRIQUETTES¹

By H. G. SCHURECHT

ABSTRACT

An automatic direct-reading laboratory scale has been designed in the Ceramic Laboratory of the Bureau of Mines, with which it is possible to weigh briquettes in about one-third the time required with balances. It is capable of weighing up to 150 grams in 50-gram intervals with an average accuracy of 0.05 gram. Although this particular scale was made for the above limits in accuracy and capacity, similar scales may be made in which this range may be modified as desired.

Introduction

Automatic direct reading scales have proved to be big time savers and indispensable to the industries, but heretofore no laboratory scales of sufficient accuracy have been made which register automatically for intervals greater than 2 grams. In the utilization of clays for ceramic purposes considerable time can be saved in testing by using automatic direct reading apparatus. It was the realization of the importance of such a scale for weighing clay briquettes, that prompted the writer to design one capable of weighing up to 150 grams in 50-gram intervals, with an average accuracy of 0.05 gram.

Construction

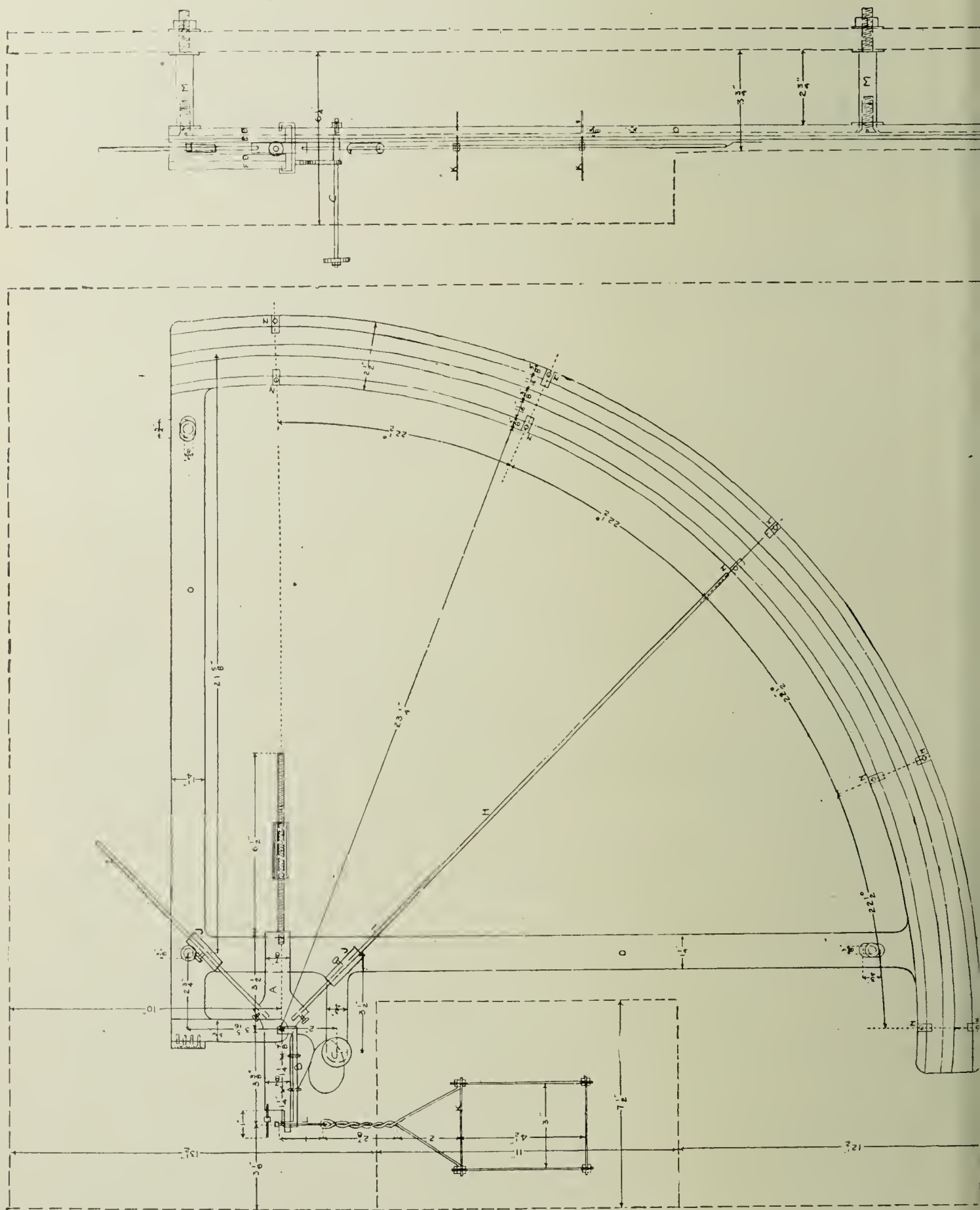
The scale herein described operates with levers similar to certain types of postal scales. Postal scales, however, have only one lever arm corresponding to the indicator lever used in the new instrument (Fig. 1). When a unit weight is placed on the pan of a scale of this type the indicator moves until the resultant force to the right balances that to the left of the main knife edge.

In a scale containing one lever the movements of the indicator for unit weights are of unequal magnitude in different portions of the stroke. As the pointer swings upward from the vertical or zero position, the movement of the moment arm to the left of the knife edge and of that to the right of the knife edge increases for the first 45° of the stroke. During the second 45° of the stroke the moment arm to the left of the knife edge decreases while that to the right increases. It is obvious therefore that the resultant force and hence the movement of the indicator per unit weight becomes less during the upper portion of the stroke.

Experiments conducted with a one lever scale of this type showed that if desirable spacing for the divisions is obtained in the lower portion of the stroke, the spacing would be too close through the upper portion. If

¹ Abstract of paper presented at the meeting of the AMERICAN CERAMIC SOCIETY, February, 1922, St. Louis, Missouri. Published by permission of the Director, U. S. Bureau of Mines.

adjusted so that the spacing for the unit divisions in the upper portion of the scale was large enough for practical purposes, the spacing in the lower portion would be so large as to limit the capacity of the scale. For a



This was accomplished by placing a second lever above and at right angles to the indicator lever (Fig. 1). When the indicator lever is vertical or at zero, the center of gravity of the second lever has a maximum moment arm and reduces to the greatest extent the resultant force and hence divisions for a unit weight. As the pointer swings upward to the right 90° , the moment arm for this lever gradually decreases to zero. Hence by adjusting the weight on the indicator lever so the spaces of the unit division in the upper portion of the stroke are sufficiently large, those divisions in the lower portion may be made approximately the same by adjusting the center of gravity by means of the weight on the second lever at the proper distance from the knife edge. This condition is obtained when the equilibrium shown in equations 1, 2 and 3 below (p. 494) exist. In other words, the center of gravity is changed to meet the condition herein expressed.

The main arms and levers of the scale are made of an alloy composed of 10% copper and 90% aluminum. This alloy has the advantage over brass or aluminum in that it is very light, hence making the instrument more sensitive than if it were made with the heavier brass, and it is more rigid than aluminum, which although light is too flexible to be used for this purpose.

Since the main levers are all made of the same material, any expansion or contraction due to temperature changes would not affect the readings of this scale. All bearings and knife edges are made of agate to reduce friction.

The entire scale is enclosed in a case to prevent air currents coming in contact with the recording apparatus (Figs. 3 and 4).

Operation and Manipulation

When a 100-gram weight is placed on the upper pan, the indicator will come to rest in an approximately vertical position, point down, which is used as the initial reading. When 150 grams is placed on the scale the needle swings approximately 90° . Hence, when a 100-gram weight is placed on the upper pan the scale will weigh between 0–50 grams. When a 50-gram weight is placed on the upper pan the scale will weigh from 50–100 grams, and when no weights are placed on the upper pan it will weigh from 100–150 grams in swinging through an arc of 90° .

Thus, in weighing a large number of briquettes it is first necessary to determine within what 50-gram range they will fall, and place the necessary weight on the upper pan. The briquettes to be weighed are then placed on the lower pan and the same is carefully released until the indicator comes to rest.

Calibration

If the scale is made according to the specified drawings, it may be adjusted by moving the weights up or down on the levers until the following

conditions of equilibrium are reached: The indicator should be approximately vertical when a 100-gram weight is placed on the pan; with 125

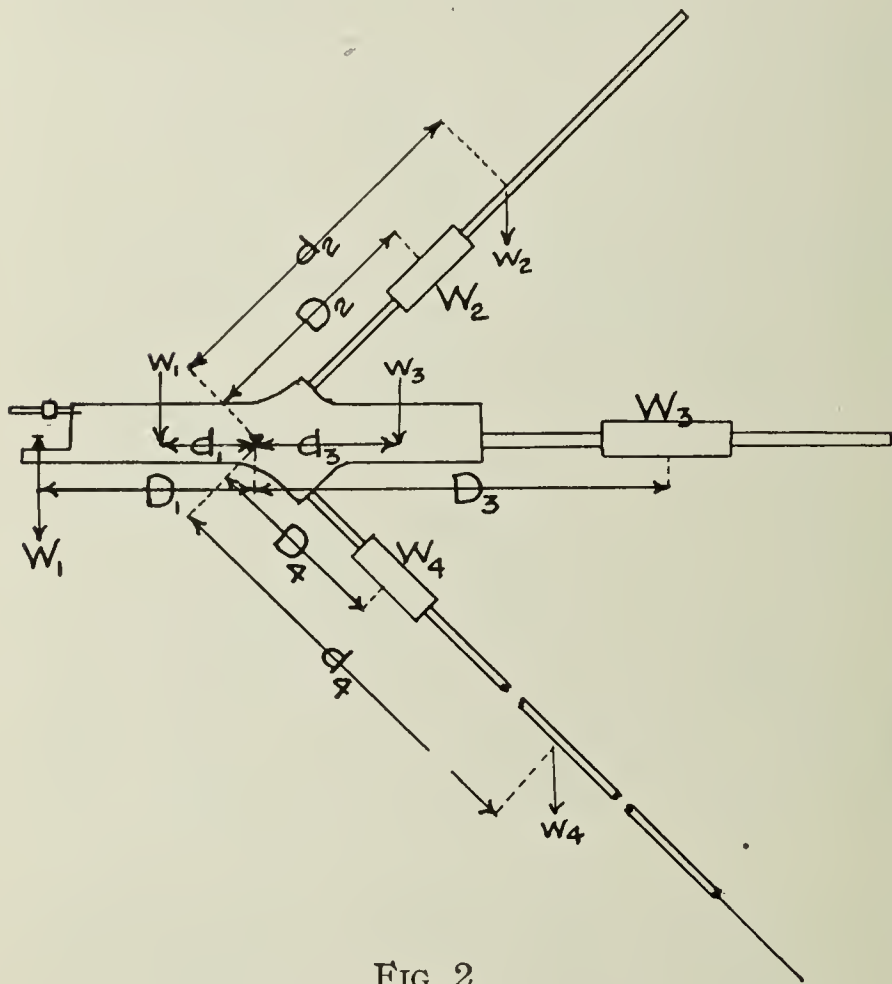


FIG. 2

main knife edge, respectively, $d_1 \dots d_4$ represent the distances of the centers of gravity of $w_1 \dots w_4$ from the main knife edge.

(1)

$$(W_1 + 100) \sqrt{\frac{D_1^2}{2}} + w_1 \sqrt{\frac{d_1^2}{2}} = W_2 D_2 + w_2 d_2 + W_3 \sqrt{\frac{D_3^2}{2}} + w_3 \sqrt{\frac{d_3^2}{2}}$$

(2)

$$(W_1 + 125) D_1 + w_1 d_1 =$$

$$W_2 \sqrt{\frac{D_2^2}{2}} + w_2 \sqrt{\frac{d_2^2}{2}} + W_3 D_3 + w_3 d_3 + W_4 \sqrt{\frac{D_4^2}{2}} + w_4 \sqrt{\frac{d_4^2}{2}}$$

(3)

$$(W_1 + 150) \sqrt{\frac{D_1^2}{2}} + w_1 \sqrt{\frac{d_1^2}{2}} = W_4 D_4 + w_4 d_4 + W_3 \sqrt{\frac{D_3^2}{2}} + w_3 \sqrt{\frac{d_3^2}{2}}$$

Since all of the above values are constant for a given design except D_2 , D_3 , and D_4 , these values may be calculated from the above equations. If these distances are too small or large for this design, the values W_2 , W_3 , and W_4 may be increased or decreased as is found necessary.

If it is desired to change the capacity and accuracy of this scale, it is simply necessary to insert new values for 100, 125 and 150 grams in equations 1, 2, and 3, respectively, and calculate the distances D_2 , D_3 , and D_4 .

grams, it should swing 45° and with 150 grams it should come to rest in a horizontal position, *i. e.*, 90° from the vertical. The scale is then calibrated into 0.1 gram divisions by placing weight on the pan and marking the different positions on the scale indicated by the needle.

The three positions of equilibrium, cited above may be expressed by the following three equations. The significance of $W_1 \dots W_4$ and $D_1 \dots D_4$ is given in Figure 2. $w_1 \dots w_4$ represent the weights in grams of the levers to one side of the

and D_4 . For example, if it is desired to change the scale so that it will weigh up to 15 grams with an accuracy of 0.005 gram or 5-gram intervals, the values 0, 12.5 and 15 should be substituted in equations 1, 2 and 3, or 100, 125 and 150, respectively, and the new distances D_2 , D_3 , and D_4 calculated. While the writer has worked only with a scale of 150-gram capacity and an accuracy for 0.05 gram, and has not determined how much the capacity and accuracy may be changed, theoretically it seems possible to vary these within wide limits by the above method.

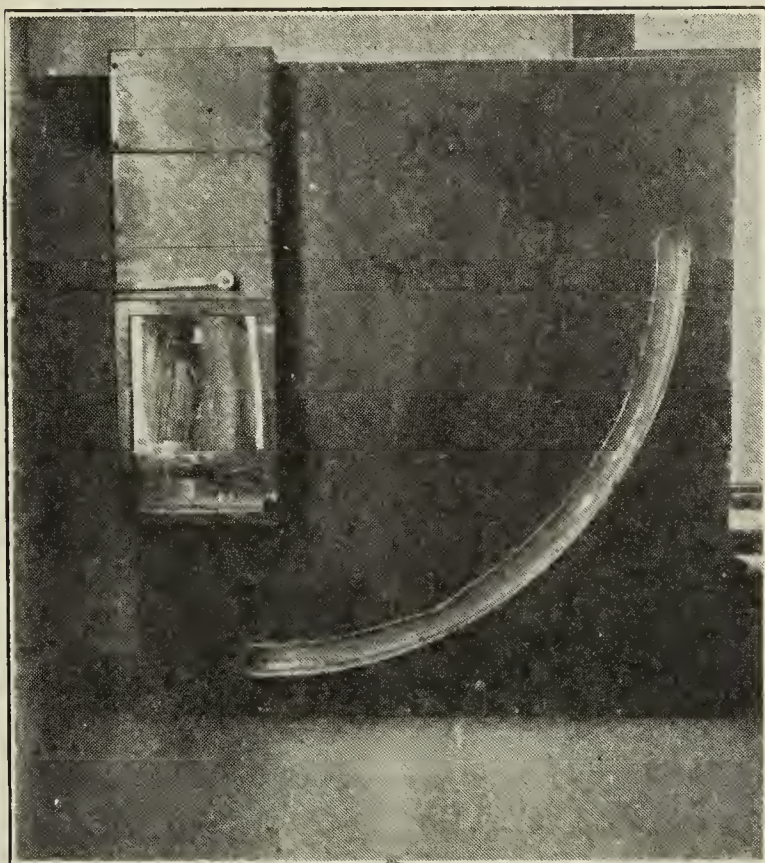


FIG. 3.—Exterior view.

Results

Where a large number of briquettes are to be tested it was found that they can be weighed on the automatic scale in about one-third the time required with balances having automatic attachments. This apparatus is ex-

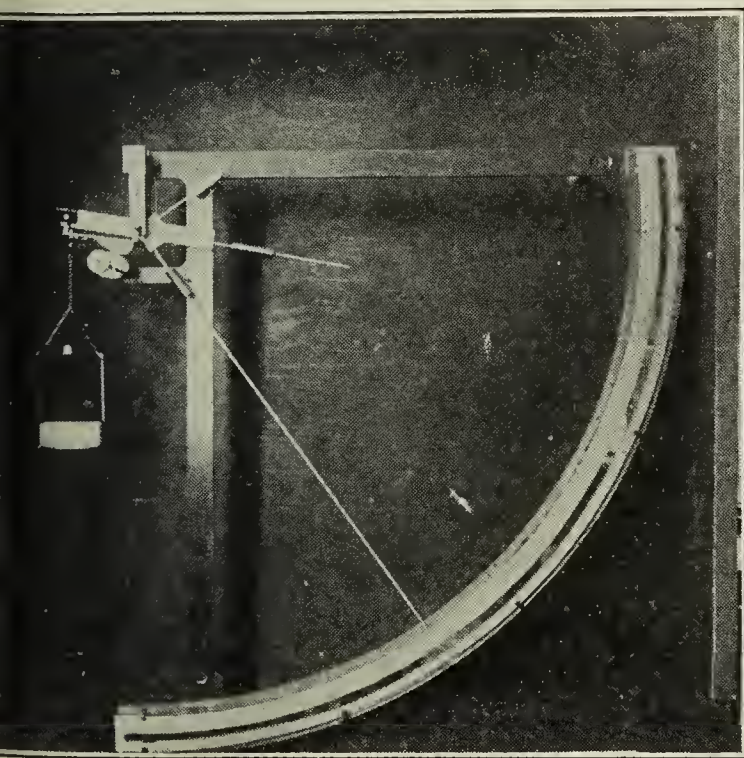


FIG. 4.—Interior view.

pensive, costing approximately \$200, but if used extensively, would soon pay for itself in the time saved. If it were made on a commercial basis, the price could be reduced considerably. To the amateur the trouble due to vibrations of the indicator before it comes to rest would be objectionable. This, however, may be largely overcome by careful manipulation. It has also been suggested that the time of vibrating of the indicator may be reduced by damping between two magnets placed in the path of the indicator.

In conclusion, the writer wishes to acknowledge his indebtedness to Mr. R. T. Stull for helpful suggestions on this work.

COMPOSITION AND PROPERTIES OF DIASPORE, BAUXITE AND GIBBSITE¹

By RAYMOND M. HOWE AND R. F. FERGUSON²

Bauxite has been used in the manufacture of refractories for many years and has given very good satisfaction under certain conditions. Aubrey and Greaves-Walker³ state that bauxite bricks give unusually good service in the metallurgy of iron, lead and copper, and in Portland cement kiln linings. Any dissatisfaction has usually resulted from its high shrinkage which is difficult to remove in the kiln.

More recently diasporé has been used in the manufacture of refractories although this material has previously been rejected in the mining of fire clay. Diasporé apparently has less fire shrinkage than the other hydrates of alumina and in that way has a marked advantage.

Before discussing the properties of the various hydrates of alumina the writers wish to summarize as briefly as possible certain articles which refer to their constitution, composition, color, hardness, specific gravity and fusion points.

Dana⁴ and Lienau⁵ divide the hydrates of alumina into three classes the mono-, di-, and trihydrates. These correspond to water contents of 12% to 14%, 20% to 24% and 27% to 35%.

Berthier⁶ regards the dihydrate as the true bauxite, for the material coming from the district of Les Baux corresponds most closely to this formula. Treadwell⁷ apparently is of the same opinion for he gives the composition of bauxite as $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$.

Cornu and Redlich⁸ consider only two hydrates, the mono- and trihydrates, and maintain that the dihydrate is a mixture of the others. Arsandaux⁹ arrives at the conclusion that the silica in bauxite is introduced as clay substance more often than as quartzite. He also states that the iron occurs as the oxide and not as the hydrate. Berthier¹⁰ concurs in the latter conclusion.

Wohlin¹¹ has undoubtedly completed the most thorough study of the constitution of the hydrates by making thermal analyses of sixteen samples

¹ St. Louis Meeting, Feb., 1922.

² Fellows, Refractories Manufacturers Association Fellowship No. 5, Mellon Institute of Industrial Research, Pittsburgh, Pa.

³ A. J. Aubrey, *Electrochem. Met. Ind.*, **4**, 466 (1907); A. F. Greaves-Walker, *Trans. Amer. Ceram. Soc.*, **8**, 297 (1906).

⁴ Dana, "A System of Mineralogy," Wiley and Sons (1911).

⁵ H. Lienau, *Chem. Zeit.*, **27**, 422 (1903).

⁶ Berthier, *Annales des mines*, **6**, 531 (1831).

⁷ Treadwell, *Kurzes Lehrbuch der analytischen Chemie*, **90** (1911).

⁸ Cornu and Redlich, *Zeitschrift für Chemie u. Ind. der Kol.*, **4**, 90 (1908).

⁹ Arsandaux, *Compt. rend.*, **138**, 936 (1909).

¹⁰ *Op. cit.*

¹¹ Wohlin, *Sprechsaal*, **46**, 719 (1913).

These samples were heated in a small resistance furnace operated under standardized conditions. The temperature of the samples was slightly lower than that of the furnace except when some decided constitutional change occurred as the temperature increased. When bauxites of the mono-hydrate type were heated they showed a decided heat absorption at 540°C while they were being dehydrated. Those of the trihydrate type showed a heat absorption at 310°C , which was their dehydration temperature. The minerals which had a composition corresponding to a dihydrate showed heat absorptions at both 310°C and 540°C . He considered that this proved that the dihydrate was simply a mixture of the other two forms, thus confirming the conclusions of Cornu and Redlich.

Wohlin also observed that there was an evolution of heat at 1070°C . This was so pronounced that the temperature of the sample exceeded that of the furnace in which it was being heated by 40°C . This was associated with a marked increase in the density of the samples, for the specific gravities increased from 3.03 to 3.70 during this action.

Klockmann¹ gives the following ranges for the composition of bauxites:

Ignition.....	12 to 40%
Silica.....	2 to 30%
Alumina.....	50 to 70%
Ferric oxide.....	3 to 25%

With these oxides are associated about 3% of titania, which appears to be characteristic.

Other data given by Dana² are as follows:

Diaspore: $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$; Al_2O_3 85.0 + H_2O 15.0 = 100.0; specific gravity = 3.3–3.5; color—whitish, grayish white, greenish gray, hair brown, yellowish to colorless; hardness = 6.5–7.0.

Bauxite: $\text{Al}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$; Al_2O_3 75.2 + H_2O 24.8 = 100.0; specific gravity = 2.55; color—whitish, grayish, to ocher yellow, brown and red.

Gibbsite: $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$; Al_2O_3 65.4 + H_2O 34.6 = 100.0; specific gravity = 2.3–2.4; color—white, grayish, greenish or reddish white; hardness = 2.5–3.5.

Bricks made from bauxite fuse at from 1565° – 1785°C .³

The terms diaspore, bauxite and gibbsite as defined by Dana will be used in describing the experimental data recorded in this paper, although Wohlin undoubtedly proved that bauxite is a mixture of the other two hydrates. The present investigation was planned in order to study the relationship between chemical composition, refractoriness, fire shrinkage, and change in porosity. The usual standard methods were employed in making the tests and will not be described.

¹ Klockmann, *Lehrbuch der Mineralogie*, 406 (1912).

² Dana, *op. cit.*

³ Kanolt, *Trans. Amer. Ceram. Soc.*, 15, 167 (1913).

Composition of Diaspores, Bauxites and Gibbsite

The materials used in the present investigation gave the following range in composition. Their complete analyses are given in Table I.

Ignition.....	9.88-28.08
Silica.....	1.36-20.50
Alumina.....	52.48-73.70
Ferric oxide.....	0.47-23.55
Titania.....	2.09-3.85
Lime.....	0.22-3.17
Magnesia.....	0.16-0.79
Alkalies.....	0.37-1.34

TABLE I
COMPOSITION OF DIASPORES AND BAUXITES

	1	2	3	4	5	6	7
H ₂ O.....	28.08	17.90	13.74	13.14	9.88	14.98	14.24
SiO ₂	9.70	18.90	13.96	20.50	1.36	17.84	5.36
Al ₂ O ₃	56.31	52.48	67.21	60.89	60.66	61.98	73.70
Fe ₂ O ₃	3.10	4.39	.75	.55	23.55	.47	2.28
TiO ₂	2.09	2.68	3.22	3.14	3.85	2.85	3.57
CaO.....	.22	3.17	.22	.43	.22	.22	.40
MgO.....	.52	.40	.36	.31	.50	.79	.16
KNaO.....	.49	.43	1.16	1.34	.37	.38	.53
Total.....	100.51	100.35	100.62	100.30	100.39	100.51	100.24

It was observed that the usual standard method for analyzing clay was not entirely satisfactory for analyzing diaspore. This material is difficult to fuse with sodium carbonate and often considerable alumina remains with the silica residue. The carbonate fusion was, therefore, dissolved in hydrochloric acid and the insoluble residue filtered off. This residue and paper were then ignited and fused with potassium bisulfate. This cake was added to the original filtrate and the silica determined in the usual manner, care being exercised to correct the silica with hydrofluoric acid.

While the precautions involve considerable extra care and time they are deemed necessary, since the chief difference in the composition of clay and diaspore lies in their silica contents.

In reviewing the results it is to be noted that the alkalies, magnesia and characteristic 3% of titania show little variation. This is also true of the lime, except in one case where the bauxite was probably contaminated in mining by the limestone with which it occurred. The ignition losses of silica, ferric oxide, and alumina varied considerably. Sample No. 5 with its low ignition loss confirms Arsandaux's theory that the iron is present as the oxide and not as the hydroxide.

Fusion Points

There was an eight cone range in the fusion points of the minerals, the minimum being cone 34. (See Table II.) By taking samples 3 and 7, which are highest in alumina content and fusion point, and using them as standard, certain general conclusions can be drawn regarding the relationship between composition and fusion point.

TABLE II
GENERAL DATA FOR BAUXITE AND DIASPORES

	1	2	3	4	5	6	7
fusion points in cones.....	41	34	42	40	42	40	42
per cent volume drying.....	...	...	...	...	...	...	...
shrinkage.....	8.3	5.5	11.6	5.8	8.4	3.7	10.2
porosity Cone 3.....	59.6	47.1	45.4	40.3	53.1	48.0	49.0
porosity Cone 18.....	42.9	31.7	38.8	36.7	8.9	31.8	46.3
ifference.....	16.7	15.4	6.6	3.6	44.2	16.2	2.7
urning shrinkage to Cone 3...	18.0	12.7	8.2	12.2	12.2	16.7	1.3
urning shrinkage to Cone 18..	42.6	30.8	29.9	16.3	55.2	38.2	16.3
ifference.....	24.6	18.1	21.7	4.1	43.0	21.5	15.0
er cent H ₂ O.....	28.08	17.90	13.74	13.41	9.88	14.98	14.24
er cent SiO ₂	9.70	18.90	13.96	20.50	1.36	17.84	5.36
er cent Al ₂ O ₃	56.31	52.48	67.21	60.89	60.66	61.98	73.70
er cent Fe ₂ O ₃	3.10	4.39	.75	.55	23.55	1.47	2.28
urce.....	Ark.	France	Mo.	Mo.	France	France	Mo.

When Nos. 3 and 4, and 6 and 7, are compared it is demonstrated that 10% of silica lowers the fusion point about 2 cones, for each of these sets of samples is remarkably similar otherwise. No. 5 shows that high iron (23.55%) does not lower the fusion point seriously when the sample is low in silica (1.36%). No. 2 would naturally fuse at about cone 40 but the high iron content (3.17%) has lowered its fusion point to cone 34. Thus, iron appears to be the worst flux in aluminous minerals; iron oxide is not a serious flux when the silica content is low and silica exerts a mild fluxing action when the iron oxide is low.

Porosity and Volume Changes

The results of the draw trial tests are given in Table III and IV. When these data are examined it is to be noted that there is a close relationship between the changes in porosity and the volume shrinkage. The average volume shrinkage from cone 3 to cone 18 was 22.6%; 15.0% was due to a decrease in porosity and 7.6% was due to an increase in the density of the substance.

There was only a rough relationship between the ignition losses and the volume shrinkages. Two samples had a very pronounced tendency to shrink—one was very high in ferric oxide (23.55%) and the other had a

TABLE III
BURNING SHRINKAGES AT VARIOUS TEMPERATURES

Cone	Temperature °C	Burning shrinkage by volume						
		1	2	3	4	5	6	7
01	1050	..	.0	8.1	12.7	9.3	..	.7
1	1100	..	4.6	8.2	12.5	11.8	..	.8
3	1150	18.0	12.7	8.2	12.2	12.2	..	2.6
6	1200	27.2	18.1	8.2	12.1	16.5	18.7	2.6
8	1250	33.0	23.0	10.6	14.3	37.6	20.7	4.0
10	1300	35.6	23.9	13.6	15.0	39.6	25.9	5.7
12	1350	40.1	30.0	16.7	15.8	41.6	26.5	9.2
14	1400	41.6	30.6	21.4	16.6	43.8	29.8	9.4
16	1450	42.4	31.5	28.6	16.6	55.4	35.3	12.4
18	1500	42.6	30.8	29.9	16.3	55.2	38.2	16.3

TABLE IV
POROSITIES AT VARIOUS TEMPERATURES

Cone	Temperature °C	1	2	3	4	5	6	7
01	1050	..	46.3	44.9	39.7	53.9	..	49.4
1	1100	..	47.5	44.6	40.1	53.2	..	48.6
3	1150	59.6	47.1	45.4	40.3	53.1	..	49.0
6	1200	54.6	42.0	43.8	37.1	49.0	47.6	49.5
8	1250	51.2	38.2	42.4	38.7	38.4	46.3	49.5
10	1300	50.0	38.6	41.5	38.3	36.4	43.8	49.1
12	1350	45.7	33.8	40.9	37.9	34.3	43.5	48.2
14	1400	44.5	32.8	39.4	35.1	31.9	40.5	48.9
16	1450	43.3	31.7	40.4	36.6	16.0	35.4	47.7
18	1500	42.9	31.7	38.8	36.7	8.9	31.8	46.3

high ignition loss (28.08%). These results lead to the conclusion that diaspores low in ferric oxide and containing several per cent of silica will shrink the least. Gibbsite high in ferric oxide and low in silica will shrink the most.

There was no apparent relationship between composition and drying shrinkage.

Summary

High alumina brick may be made from three ores, diaspore, bauxite and gibbsite. Diaspore is the monohydrate, gibbsite the trihydrate, and bauxite is a mixture of the two. These ores vary considerably in chemical composition except in magnesia, alkalies, and titania. Their fusion points are lowered most by lime and least by ferric oxide and silica. The burning shrinkages of the minerals high in silica were lowest, while those high in ferric oxide shrunk the most. Gibbsite had a higher burning shrinkage than diaspore.

DIASPORE CLAY OF ARKANSAS AND MISSOURI¹

By D. C. WYSOR

Slightly less than a decade ago I spent about two years in the Arkansas bauxite fields. While there I had occasion to make a great many chemical analyses of the various grades of ore. During the course of operations I made, so far as I am aware, the first discovery of diasporite to be reported in this country. In 1915, I believe it was, I sent a short technical paper on this subject to economic geology. Arkansas diasporite exists in certain of the bauxite oolites only and probably constitutes not over 1% of the deposits. It is only of mineralogical interest. The rest of the hydrate composing the ore bodies is of the tri- or gibbsite type. You are, of course, familiar with the origin of the term bauxite, and know that it is generally applied to the ores of aluminum.

By very careful means of separation a few ounces of diasporite and diasporitic oolites were separated from time to time. Complete analyses of these were made and recast into corresponding mineralogical percentages with highly satisfactory results. These were grouped into a series showing on the one end practically pure diasporite and on the other essentially pure gibbsite. The question as to whether bauxite as a separate mineral actually existed was indeed puzzling. As such, certainly it cannot be recognized in Arkansas, and, so far as I know, it has never been isolated. However, I have always held that it did exist in Arkansas, at least, because we are reasonably certain that the diasporite there is subsequent to the gibbsite, having resulted from it through that metamorphic process characteristic of the higher hydrates of aluminum. And it seems only logical to me that in Nature's process of reduction from the tri- to the mono-hydrate, only one molecule of combined water would be lost at a time. I readily grant that the di-hydrate might be a very unstable compound that would probably serve only in the transition stage.

As indicated, therefore, diasporite appears to be a more stable compound than gibbsite, and if there is any bauxite mining going on in Arkansas 10,000,000 years from now, I have no doubt but that the hydrate produced will be, in reality, diasporite.

In passing I might say that the Arkansas diasporite has about the hardness and specific gravity that Dana² gives to the crystalline mineral, but, unlike the latter, it is amorphous. It is also accompanied by a high percentage of iron and titanium.

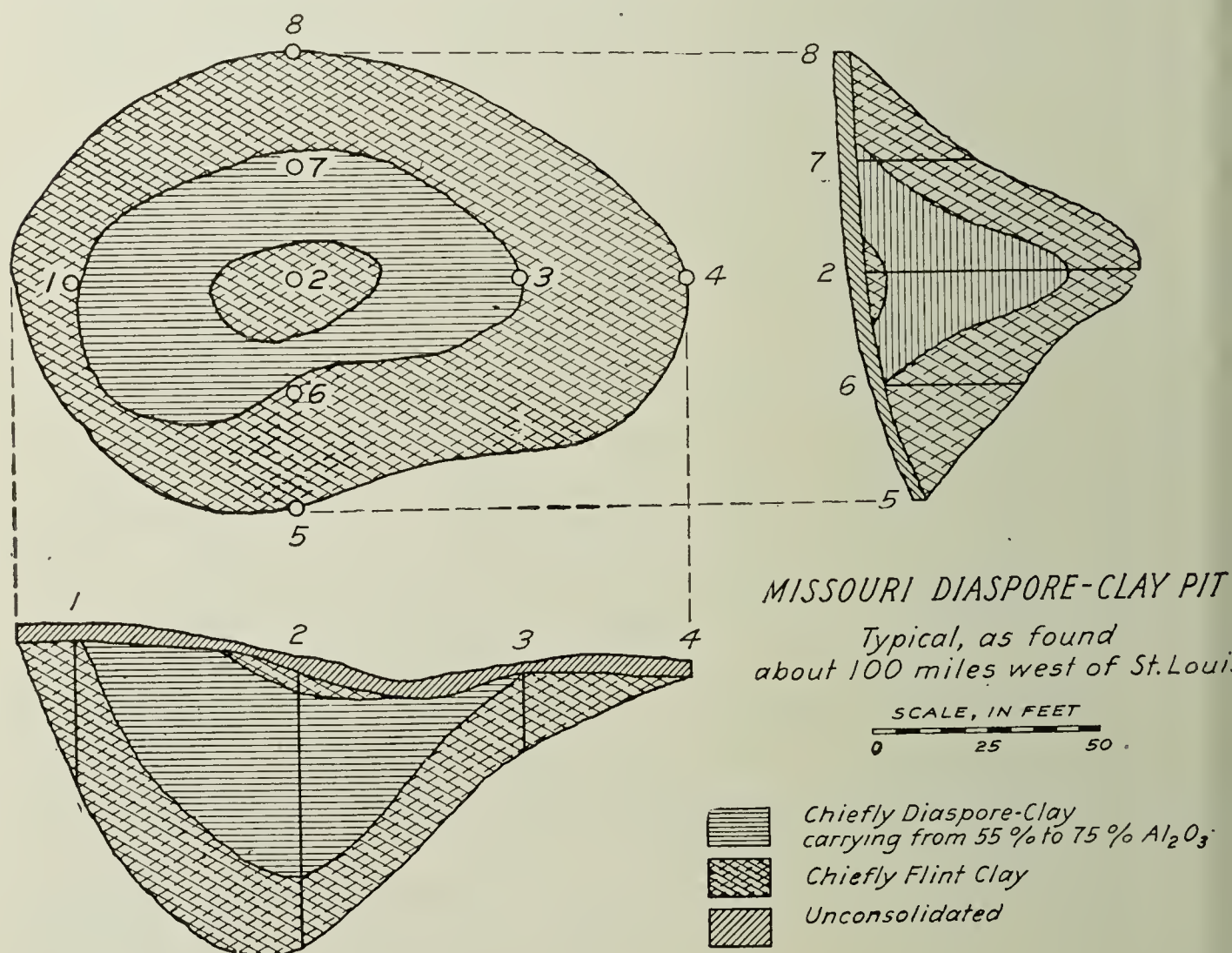
The commercial deposits of diasporite of Missouri, I think, are not at all similar in point of origin to the mineralogic diasporite of Arkansas. In Missouri I feel that we must look to some form of sedimentation. Diasporite here is always associated with these carboniferous flint or semi-

¹ Received July, 1922.

² Dana, *op. cit.*

flint clays, which, as you know, occur in well defined kettle shaped depressions. My idea is that the clay was deposited as a soft sediment (probably I should say a mechanical sediment) and the diaspoire resulted from it during the period of solidification. I do not wish to discuss the point as to where the clay came from or how a normal aluminum silicate can be converted into a monohydrate. I shall leave it to the other fellow to prove that I am wrong.

Commercial quantities of diaspoire in Missouri are found in a very limited number of these pits. No pit will ever consist of diaspoire alone, although in some cases this material will make up the bulk of the core. It is always



surrounded by the clay. As a rule the diaspoire is more or less stratified in the deposit, a normal succession being: Clay, low grade diaspoire, high grade diaspoire, low grade diaspoire, clay, low grade diaspoire and so on. Every gradation can be found between clay and diaspoire carrying 80% alumina (85% Al_2O_3 is the theoretical limit). In mining practice, two or three grades, depending upon alumina content, can be readily distinguished.

Missouri diaspoire is of several distinct types physically. With certain minor exceptions all appear to be amorphous. Even so, there must be some difference in the arrangement of the atoms of the molecules as between Missouri and Arkansas diaspoire. A certain acid treatment which readily dissolves Arkansas diaspoire has little effect on the Missouri member.

As stated above, the accessory constituents iron and titanium, are high in case of Arkansas diaspore. In Missouri, the iron is low, titanium is fairly high with the other accessory components rather normal. The highest grade material which I found in Arkansas would compare about as follows with the normal Missouri product.

	Arkansas	Missouri	(Pure dias.)
H ₂ O.....	14.00	13.50	15.00
Al ₂ O ₃	71.00	65.00	85.00
SiO ₂	1.00	15.00	...
TiO ₂	5.00	4.00	...
Fe ₂ O ₃	9.00	1.20	...
CaO.....	...	.10	...
MgO.....	...	.20	...
K ₂ O and Na ₂ O.....	...	1.00	...
	<hr/> 100.00	<hr/> 100.00	<hr/> 100.00

All of the silica in the Arkansas type is in the combined state as in a kaolinitic variety of clay which accompanies the deposits. Under normal conditions there is little or no free silica present in Missouri diaspore. The silica present is in the associated flint or semi-flint clays.

Missouri diaspore of the composition as above given will fuse at cone 38 or 39. Material carrying 70% to 75% alumina should fuse at cone 41 or thereabouts. A 55% diaspore will fuse at about cone 37. There seems to be about one cone of difference for each 4 or 5 per cent alumina, but of course the actual fusion point is influenced by the relative proportions of the respective accessory constituents. The highest grade bauxite will probably fuse at cone 39 to 40.

I have seen diaspore from a number of other localities in the United States that resembled the Missouri material, but so far as I am aware Missouri is the only place in America, and probably the only known place in the world, where high grade diaspore could be mined and shipped in appreciable commercial quantities. At best any diaspore is comparatively rare. It is possible to select specimens of Missouri diaspore carrying 80% or more alumina, but shipments carrying 70% to 75% alumina are about the highest grade practicable to attain. Such a product as this is very rare. Fifty to 60% ore is much more abundant.

That Missouri diaspore is becoming rapidly more popular in the refractory field is evidenced by the much larger tonnages now being consumed. That it is superior to bauxite in the manufacture of refractories I think there can be no doubt. The higher refractoriness which can be obtained and the lower shrinkage of the diaspore are certainly strong points in its favor. Diaspore carrying 9% or less silica appears to be in greater demand than bauxite in the abrasive industry.

Further Discussions on Diaspore

By D. C. WYSOR¹—A Missouri diaspore-clay deposit, or pit as we may choose, typical as to size and shape and as to quality of material, might be briefly summarized as follows:

Surface diameter, 75 to 250 feet, average about.....	125
Maximum depth, 50 to 150 feet, average maximum about.....	60
Average depth of average pit about.....	25
Average tonnage of average pit about.....	15,000

divided probably about as follows:

Smooth clay (chiefly flint with some bond).....	8,000
Abrasive grade diaspore (70% Al_2O_3 and 10% or less SiO_2).....	250
No. 1 grade diaspore (65% Al_2O_3 and 15% SiO_2).....	750
No. 2 grade diaspore (60% Al_2O_3 and 20% SiO_2).....	2,000
No. 3 grade diaspore (55% Al_2O_3 and 25% SiO_2).....	4,000

These relative tonnages will, of course, vary greatly from point to point. Probably the majority of diaspore pits have little or no abrasive grade that can be selected in commercial quantities. In exceptional cases, however, the abrasive type may constitute a considerable proportion of all the diaspore in the deposit, though the No. 2 and No. 3 always predominate.

The above grades, with their respective standards of quality, I have originated for practical convenience. The term "Burley" Clay, which I do not like because of its loose usage, is generally applied in this section, as you no doubt know, to clay carrying around 45% to 50% or possibly 55% alumina. The No. 3 grade will fuse at about cone 37, while the abrasive grade will fuse around cone 42. The best grade flint clay in this section will fuse at cone 34.

A diaspore-clay pit is usually roughly elliptical. The deepest part of the pit is seldom in the center, but often about half way between the center and one side. As a result of this eccentric condition, the wall on one side of the deposit will dip very steeply (probably as much as 90 degrees at the surface) while on the opposing side of the deposit, a gentle slope of 20 to 25 degrees may be encountered.

The wall rock of all of the pits in this section is sandstone, which is loosely cemented. In some cases where the sandstone is very argillaceous and badly weathered, it amounts to nothing more than a soft impure clay which may cause considerable trouble by caving during mining operations.

The diaspore-clay pit, then, can best be realized as a kettle shaped mass bounded at all points of contact with sandstone. The surface of the pit will be covered, on an average, with about four feet of soil, sand, gravel and residual chert and hardpan. The gradation between the sandstone wall

¹ Received November, 1922.

and the flint clay, which always forms a shell from 5 to 20 feet or more in thickness about the diaspoire core, is generally sharp, though it is often gradual on one side of the deposit and sharp on the opposing side.

Within this shell of flint clay will be found any or all of the above mentioned grades of diaspoire together with some layers of flint and bond clays. The entire mass is usually roughly stratified. The gradation between the various grades of diaspoire and clay is often fairly sharp, but generally it is gradual.

Diaspoire Clays of Missouri

By I. A. KRUSEN:—This discussion will be limited to the east-central district of Missouri, producing only non-plastic or flint fire clays. Roughly speaking, this district is circular with a diameter of about 25 miles including the following towns: Belle, Owensville, Lesley and Cuba.

The deposits are not confined to a particular geological horizon or period occurring in or on rocks of the Pennsylvanian, Ordovician, Silurian and Mississippian formations. They do not occur as stratified beds but as massive deposits filling the crater-like depressions in the sandstone or limestone. These basins occupied by the flint clay vary from 50 to 250 feet in diameter, and from 15 to 100 feet in depth.

The total number of these pits has been estimated at 7,000. About 200 of this number have been worked. They are estimated to average from 5,000 to 10,000 tons in each pit, although some contain as much as 100,000 tons. About $\frac{1}{4}$ of this area contains pits furnishing diaspoire. There is great variation in size of pits and content of each. The following worked-out pit may give some idea. It contained 5,000 tons divided as follows: 3,000 tons of smooth flint, 2,500 tons of burley flint and 500 tons of diaspoire. These three divisions of flint clay occur as follows:

Smooth flint—found alone, with burley or both burley and diaspoire.

Burley flint—found either with smooth or with both smooth and diaspoire.

Diaspoire—combined with both smooth and burley.

Flint clay mining is carried on by the open pit method. The overburden which is not usually over 5 to 15 feet is stripped back by teams and scrapers exposing the top of the flint. It might be of interest to note that the first layer or lining of the bowl or pocket is always smooth flint, varying from 2 to 4 or more feet in thickness, the balance of the deposit sometimes containing burley or both burley and diaspoire.

The flint clays usually are very pure chemically, have a compact dense structure and break with a sharp conchoidal fracture. When ground and mixed with water they have little plasticity. The following is a typical analysis of the smooth flint:

Silica.....	44.02	Calcium.....	trace
Alumina.....	40.06	Magnesia.....	.11
Iron oxide.....	.49	Alkalies.....	.45
Titania.....	1.65	Loss on ignition.....	13.46
		Total.....	100.24

The smooth flint clays will soften from cone 34 to 35.

Air shrinkage.....	5%
Burn shrinkage.....	5%

This flint is used together with plastic fire clay in high grade fire brick and some fire clay shapes.

Burley flint is rougher, has a higher fusing point, and is in general better refractory. The following analysis shows a typical burley flint:

Silica.....	30.46	Magnesia.....	.20
Alumina.....	54.09	Alkalies.....	.50
Iron oxide.....	1.35	Ignition.....	12.95
Lime.....	1.37		
		Total.....	100.92

It has a fusing point of cone 36 or better. Both the flints have a high shrinkage. Burley flint is used in high grade refractory brick and tile.

The most recently discovered and important associate of the flint clay is diaspore clay, a variety rich in alumina, formerly discarded because of its rough ashy texture. The presence of this rough type of clay has until recently been regarded as detrimental or worthless and today some abandoned pits may be found where large bodies of it were left. The peculiar texture of the diaspore clay and its common association with the flint clay, frequently as a core near the center of the deposit or as rounded boulders in the overlying weathered clay, aroused the interest of W. S. Cox of Cuba, Missouri, who had for several years been a producer of flint clay. Probably it is through his interest and work that we are indebted for the importance of this clay is fast assuming in the refractories and other industries today.

Diaspore clay is found in the flint area extending from a few pits around Gerald to more numerous deposits located around Owensville and Bell. Most of the clay shipped has been taken from the above described country and within a distance of three or four miles from the Rock Island Railway which traverses this district.

A few deposits have been located at Cuba and shipped via the Frisco Railway. It is not improbable that other deposits will be discovered and worked as the higher price obtained for this clay permits of a much longer haul to the railroad.

An average analysis is as follows:

	Average	High Al ₂ O ₃
Ignition.....	13.70	14.84
Silica.....	12.72	2.80
Alumina.....	68.39	78.30
Iron oxide.....	1.05	1.26
Lime.....	.20	.20
Magnesia.....	.12	.30
Titania.....	3.80	3.80
	<hr/>	<hr/>
Total.....	99.98	101.50

As a general rule the diaspore clay is located in the center of the pit much like the yolk of an egg.

The structure of a deposit is very similar to an egg. The rim rock or outside shell is usually sandstone, and surrounds a layer of white flint extending from a few feet in thickness to a solid deposit of flint. Inside the pit wall is found the burley clay and diaspore, usually in layers varying in thickness from a few inches to ten or more feet. These layers seldom lie on a horizontal plane but usually tilt at an angle from a few degrees to almost perpendicular. In some instances smooth clay is also found between layers of diaspore or diaspore and burley.

The tonnage of diaspore found in the different pits may be as low as 100 tons; it may reach 10,000 to 20,000 tons in a few cases.

Discussion¹

R. M. HOWE:—This subject has attracted considerable interest recently and I would like to hear about the occurrence of diaspore in the flint clays of Pennsylvania.

A. F. GREAVES-WALKER:—The occurrence of high alumina clays and burley flint clays in Kentucky and Pennsylvania, especially in Kentucky, are very similar to the formations in Missouri, except that the lenses of clays in the Eastern states are tremendously large as compared with Missouri. In northeastern Kentucky; in one or two instances where the occurrence of this clay was noted, the deposits were exactly the same as the Missouri diaspore clay, occurring in the center of a very large lens.

The deposits are the shape of an egg, that is, small at the top, then enlarging and tapering towards the bottom; the shell of the egg-shaped diaspore deposit is sandstone. Inside of this sandstone shell, or as we call it, the rim, because it appears on the surface as a rim of rock, comes the white flint clay—positioned similarly to the white of the egg, and in the center comes the diaspore like the yellow of the egg. I do not know about Pennsylvania but I presume the deposits are very much the same.

¹ Refractories Division, St. Louis meeting, Feb., 1922.

J. S. McDOWELL:—So far as I have been able to observe, there is no similarity between the diaspora occurrences in Pennsylvania, or rather, the nodular clay, and the diaspora clay in Missouri. The occurrences of this nodular clay have been known for a great many years. Prior to 1900 it was not used; on account of its rough appearance, it was considered poor clay and thrown away. Early in this century the fact was discovered that it really was of exceptionally good quality and the mine owners went over the old gob piles and recovered the nodule clay.

A great many of the mines in Clearfield County contain more or less nodule clay. In certain districts the nodule seems to occur about the center of the bed, but in other areas it is at the top. In the nodule clay the alumina content will vary from about 38 to a little over 50%.

R. M. HOWE:—Do you regard the nodule clay of Pennsylvania as being similar in character to the burley clays and diaspora of Missouri?

J. S. McDOWELL:—The nodule clay resembles the burley clay more than anything else. I do not believe there was any suggestion until recently that the nodules might consist of diasporas but it is very probable that they do.

A. B. CHRISTOPHER:—In the vicinity of Owensville, Mo., diaspora clay occurs uncovered like big flat boulders; it is not necessary to dig at all, just break them up and load them on to wagons.

A. F. GREAVES-WALKER:—We found in Missouri diaspora deposits exposed by erosion. It occurred to me that possibly in Pennsylvania, after observing some of the Kentucky deposits, the same thing had occurred. Where these deposits are exposed, that the top deposit of clay may have been eroded away, bringing the nodular clay to the top. The boulder deposits in Missouri are the result of the weathering of the deposits that have been eroded at the top. If these deposits run as high as 80% alumina they do not weather very rapidly, but if they get below 60% they weather comparatively fast; therefore, when weathering takes place on the surface of one of these deposits of mixed high and low grade material, the low grade diaspora disappears leaving the high grade boulders on top, as they are extremely hard and resist the weather.

I should like to ask Mr. Howe if he has information on the effect of titania on the melting point and vitrification.

R. M. HOWE:—While I have no definite information regarding the fluxing power of titania in diaspora, it would appear, by analogy, to be low. In the first place, alumina, iron oxide, and titania are very closely related from a chemical standpoint. It is also known that titania is a mild flux in clays, but that its activity is less in those of the higher alumina content. One per cent of titania is capable of lowering the fusion point of normal clay only $\frac{1}{2}$ cone and, consequently, would lower the fusion point of commercial diaspora scarcely more than $\frac{1}{4}$ cone, the amount depending upon the silica and flux content.

So far as vitrification is concerned, it should be borne in mind that very open burning flint clays carry as much, or even more titania, than the dense burning plastic clays; consequently its action is no different than that of any other flux. Vitrification is probably more closely associated with certain physical properties, such as size of grain and plasticity.

A MEMBER:—Does repeated firing at high temperature cause continued shrinkage?

R. M. HOWE:—Before answering that, I wish to ask which material you have in mind in your question?

A MEMBER:—Either material, diaspore or gibbsite.

R. M. HOWE:—It is extremely difficult to completely remove the shrinkage of gibbsite. With its high water content a great many pore spaces remain to be filled by the shrinkage of the clay. It is necessary to raise it to a temperature higher than that at which it will be used if shrinkage in service is to be avoided, utilizing perhaps an electric furnace.

The shrinkage of diaspore is less than that of gibbsite as might be expected from its lower water content. It seems to depend also upon the silica, being low with high silica. No unconquerable difficulty should be experienced in the removal of shrinkage from this material.

THE EFFECT OF HEAT-TREATMENT AND COMPOSITION OF SEMI-PORCELAIN BODIES ON CRAZING

BY IRA E. SPROAT¹

ABSTRACT

Limits of Investigation.—The investigation was confined to practical semi-porcelain bodies and glazes, therefore, the results may be applicable only to this branch of the whitewares industry.

Effect of Thickness of Glaze.—The thicker the glaze the greater the tendency to craze. The glaze on several pieces of dinner ware may appear to the eye to be of uniform thickness, but still have sufficient variation in thickness as to show difference in crazing behavior. It being impossible to obtain a uniform thickness of glaze by hand dipping there is a need for a mechanical dipper. An improved type of biscuit kiln which will produce ware with a uniform absorption is another need.

Effect of Glaze Composition.—When sufficient change was made in the composition of a typical semi-porcelain glaze to cause a marked decrease in its crazing tendency it was at the expense of other desirable properties.

Effect of Body Composition.—The addition of 10.0% to 20.0% of "Hercules" clay to a general ware body greatly decreased its tendency to craze. No other change in body composition was found feasible, for when the change was sufficient to cause a decrease in the crazing it was at the sacrifice of other essential properties.

Effect of Variation in Absorption.—Contrary to the general opinion among potters the tendency to craze was not increased by every increase in absorption. An absorption of about 7.0% to 12.0% showed the most resistance to crazing.

Effect of the Time-temperature of the Gloss Burn.—Tendency to craze is decreased by increasing the maturing time-temperature portion of the gloss burn.

Introduction

It is interesting, upon asking a group of practical potters regarding their opinion of the cause and cure of crazing, to note how divergent are the methods of attack employed, and how widely dissimilar are the points of view. A majority of the potters of a conservative turn of mind will insist that they are having little or no crazing, at the time expounding the merits of the present plant methods with a gravity matched only by their conviction that "all is well in the best of possible worlds;" a few will temper their seriousness with a burning irony, and others will issue a flaring challenge that will contrast vividly with the complacency of the majority, insisting that the time has come when the American potter must improve the quality of his ware.

Surely if any ceramic product should be free from crazing it ought to be the dishes on which is served our food; a seeming necessity from the standpoint of health, if for no other reason.

The results given in this report cover a period of three years of research and observation in some of the leading semi-porcelain factories in the country. The entire work was conducted under factory conditions and confined to practical general ware bodies and glazes. Therefore, it must

¹ Presented at St. Louis Meeting, February, 1922.

be remembered that the conclusions drawn from this series of investigations may only be applicable to this particular whiteware industry.

Thickness of Glaze

It is well known that the thicker the glaze the greater the tendency to craze, but there is very little information to be obtained from a study of the literature on the subject or from the experiences of the average potter, regarding the degree, to which the thickness of a glaze influences its crazing behavior. Therefore, it was thought best to give this problem first consideration as it may have marked influence on other factors affecting the crazing problem.

Preparation of Trials.—Sufficient clay to make 48 standard 5-inch plates (trade size) was taken direct from the pug mill and wedged by hand in order to assume a uniform body composition for the entire set of trials. The plates were jiggered, dried, and finished in the usual way, then fired in the same horizontal plane on the same car in the Dressler tunnel kiln to cone 8. The firing time was 96 hours and the average absorption of the trials was 8.9%. In order to be doubly sure that each plate would have the same absorptive power when dipped they were soaked in water for five hours and then wiped dry on the surface.

Seven glaze batches were made up weighing respectively 27, 26, 25, 24, 23, 22, and 21 ounces to the pint. Six plate trials, having previously been soaked in water, were dipped in each glaze, care being taken to dip each piece in the same manner. The plates were then gloss fired to cone 4 in the second ring of a periodic kiln. The time of firing was 24 hours. These trials were then tested for crazing.

Crazing Test.—In a prior investigation of various crazing tests, the following was found to give best and most consistent results, and therefore it was used throughout this series of investigations.

The trials were heated in an electric oven to 125°C, then quenched in ice water, this repeated three times to compensate for any uneven heat distribution within the oven. At the end of the three quenchings the plates were examined for crazing, and those that had not crazed were heated to 150°C and quenched three times. Likewise the trials not crazing at this temperature were heated to 175°C and quenched three times. Those trials not crazing at this temperature were tested at 200°C. The final treatment being at 225°C.

Results of Test.—The average crazing behavior of the six trials with even weights of glaze is given in Table I.

It can readily be seen that a glaze may not appear to be too heavy nor too light but still vary in thickness to such a degree as to cause a decided variation in crazing. The facts bear sufficient witness that the thickness

of the glaze is a very important factor, and must always be considered in the control of crazing in the factory, as well as in the study of any crazing problem from a purely technical standpoint. In other words conclusions drawn from a series of crazing tests are valueless unless the thickness of the glaze is known to be the same throughout the experiment.

Specific attention is called to the fact that even after taking every precaution possible to produce a uniform thickness of glaze in each set of trials there were six plates out of the 42 which did not show consistent crazing behavior. These results are noted under the heading "Remarks" in Table I. After examining under a microscope the thickness of the glaze on

TABLE I

No.	Weight of glaze, oz. to pt.	Crazed at	Appearance of glaze	Remarks
1	27	..	Very thick	Crazed when taken from kiln
2	26	125°	Heavy around foot	2 crazed before testing
3	25	175°	Good	2 crazed at 150°
4	24	200°	Good	
5	23	225°	Good	2 crazed at 200°
6	22	O. K.	Dry on edges	
7	21	O. K.	Very thin glaze Very dry	

these seeming erratic trials, and comparing it with that of the other plates in the same group, it was plain in five cases out of the six that the difference in crazing behavior in the same group could be attributed to a difference in the thickness of the glaze.

It was thought that inability to obtain a uniform thickness of glaze was possibly due to soaking the trials in water before dipping, therefore a second test was made. This time two dozen 5-inch plates were fired in the same sagger in the third ring of a periodic kiln. The heat-treatment was cone 7, and the absorption 9.2%. These trials were not soaked in water but given to an expert dipper just as they came from the biscuit kiln. The dipper was given instructions to dip the two dozen plates in exactly the same manner. After gloss firing in the same sagger to cone 3 and testing for crazing we found that we had the same irregularity in thickness of glaze, with the resulting variation in crazing behavior, as was obtained in our first test.

The inevitable conclusion is that, due to the human element entering into the dipping process, it is impossible to produce ware with the same thickness of glaze even though it has the same absorption. When one considers the fact that under the best kiln conditions the absorption of the ware which goes to the dipper will vary from 6.0% to 11.0%, it is not surprising that in the average general ware plant the thickness of the glaze on the

ware varies from a very thin glaze, slightly dry on the edges, to a thick one which appears thick only around the foot.

When viewed solely from the standpoint of crazing it is far from good dipping, for the glaze should be uniform in thickness, and just as thin as it is possible to make it without showing dry edges or dry spots on any portion of the ware in order to produce a product with the least tendency to craze. Since these conditions are not possible under present day commercial methods of manufacture, what *is* the solution? How can the thickness be controlled?

An improved type of kiln that would produce dinner ware with a comparative uniform absorption, (2% max. variation) would be a great aid. If the hot zone of the Dressler tunnel kiln was increased 20 or 30 feet with an increase in the total length of from 50 to 75 feet, and the width of the tunnel decreased considerably, we would have a kiln that would closely approach the ideal. If 18 to 24 hours were added to the firing schedule of the ordinary periodic biscuit kiln, far better results would be obtained.

Another aid would be a mechanical dipper which would eliminate the human element from this important process. Such a device would make it possible to control the thickness of the glaze. The variable absorption of the ware could be overcome by passing the ware through water before it entered the dipping machine. Five minutes before a modern printing press or a cigar machine, or hundreds of other mechanical accomplishments of the past decade, should convince one that such a simple operation as dipping dinner ware can be done mechanically and to perfection.

It seems to us that the mechanical dipper would be an ideal problem for coöperative research, and would do much for the advancement of the pottery industry. Such a machine would not only go a long way toward solving the crazing problem but would entirely eliminate a number of other vexing ills so prevalent in this industry, and directly or indirectly traceable to the dipping department.

With improved type of tunnel kiln capable of producing biscuit ware with a comparative uniform porosity, and mechanical dipper which would produce a uniform thickness of glaze are devices of the future. We hope that these mechanical problems will be taken up by the potteries in the near future and pushed to a successful conclusion. We feel that much stress has rightly been laid on the importance of the thickness of the glaze coating, and that it should receive careful study by every semi-porcelain manufacturer.

Glaze Composition

Since the rules formulated by Dr. Seger for decreasing crazing by changes in glaze composition have been generally accepted as reliable and are well

understood by the average potter, it is needless to consider this phase of the problem in this report. However, there is little published data regarding the effect such changes will have on other properties of the glaze which must always be considered in the development of a good commercial semi-porcelain glaze. A glaze may be free from all defects but still could not be classed as a practical semi-porcelain glaze. A good practical glaze must possess the following properties, besides being free from defects:

1. Good fluidity from cone 1 to cone 6.
2. Maximum gloss at cone 1.
3. Must mature at cone 1 and show no signs of an egg shell texture at this heat treatment.
4. Must not overfire at cone 6.
5. Must not pin mark in the decorating kilns at cone 012.

Details of Test.—The following practical semi-porcelain glaze was used as the basis for these tests:

0.027 Na ₂ O		
0.202 K ₂ O		
0.422 CaO	0.256 Al ₂ O ₃	0.24 B ₂ O ₃
0.213 PbO		2.354 SiO ₂
0.136 ZnO		

Three series of ten glazes each were compounded as follows:—Series 1: the flint content of the base glaze was increased in increments of 0.07 equivalents. Series 2: boric acid was increased at the expense of the silica in increments of 0.03 equivalents. Series 3: barium carbonate was substituted for the white lead in increments of 0.01 equivalents.

All thirty glazes were weighed out separately and compounded so as to weigh 26 ounces to the pint. Ten 5-inch plate trials having been soaked in water for five hours and then wiped dry were dipped in each of the above glazes. All trials had the same absorption as if they had been fired in the same portion of the biscuit kiln. The glazed trials were dried and fired to cone 1 in the third ring of the gloss kiln; six of the fired trials from each glaze were then tested for crazing.

Stilt Marking.—The glazes were tested for stilt marking by placing a number of stilts on two trials from each glaze and firing them in the back top of a decorating kiln to cone 012.

Fluidity at Cone 1.—From lack of a better method the viscosity of the glaze was tested by scratching two of the trial plates of each glaze just after being dipped. Four marks or scratches, varying in width from knife edge to one quarter inch, were placed on trials from the center

the edge of the plates, care being taken not to move the plates after scratching until the glaze was dry.

The degree to which the glaze filled these cut places during the gloss fire at cone 1 was compared with similar trials made from the base glaze fired under the same conditions. In this way the relative fluidity of the test glazes was determined.

The principal property of a good commercial semi-porcelain glaze, aside from being free from defects, is its ability to flow at the minimum gloss heat. Good fluidity is absolutely necessary, for under present factory conditions of dipping, the glaze on a majority of the ware is cut by handling or is far from being uniform in thickness. In other words the glaze must have sufficient fluidity to cover up all minor defects in the glaze coating.

Summary of Results.—When sufficient change was made in the glaze composition to produce any marked decrease in crazing behavior, the glaze did not possess some of the other properties so essential to a practical commercial glaze. The glazes that showed the least tendency to craze were the high silica glazes, but these were too viscous and did not flow readily at cone 1.

The results of these tests made it evident that the fluidity of the glaze on one side and stilt marking on the other, determined to a large degree the possible variation in glaze composition. This probably explains why the glazes used by the leading general ware plants show but slight variation in molecular composition.

We do not wish to create the impression that a good practical glaze could not be compounded which would have a less tendency to craze than the base glaze used in this investigation. Quite to the contrary, we are of the opinion that we would have had better success, if we had continued this preliminary investigation in other directions.

Body Composition

A number of preliminary investigations of various changes in body composition were made, but as a detailed discussion of the results would only tend to obscure the main issue rather than to clarify, only a brief summary of the results will be given.

These tests plainly indicated that the composition of a practical semi-porcelain body was also limited by factory conditions just as was found in case of glaze composition. It was perfectly evident that under present day methods of manufacture in all the general ware industries in the United States (with the probable exception of one or two where quality and not quantity is the foremost consideration) the composition of the body is limited to comparatively narrow variations. This is due to the demand

for the whitest body possible with maximum strength in the clay state in order that it can be handled with speed without causing an excessive biscuit loss.

The color of the finished product and the transverse strength of the body in the clay state are the two paramount factors which make it very difficult to make sufficient changes in the percentage proportions of the usual raw materials to produce any marked decrease in the tendency to craze.

Investigations have shown that by the use of from 10.0% to 15.0% of a new clay from Missouri, sold under the trade name of "Hercules," a good practical body can be made free from crazing.

"Hercules" clay is neither a ball clay nor a china clay but a cross between the two. It has a modulus of rupture of 325 pounds per square inch, a drying shrinkage of 6.0% and a total shrinkage of 14.0% at cone 8. It has a silica content of 61% which explains its most remarkable property, that of decreasing crazing.

The effect of substituting "Hercules" clay for a portion of the ball clay and china clay in a semi-porcelain body is plainly shown in the investigation given below.

Composition of Bodies.—The percentage compositions of the bodies used in this series of tests are given in Table II. These bodies are all practical general ware bodies, and are being used today with marked success. The percentages given in Table II were figured from the scale weights, no allowance made for moisture.

TABLE II

Material	A	B	Body no. C	D	E
Flint.....	34.05%	32.16%	31.10%	32.44%	35.0%
Feldspar.....	14.00	14.20	12.50	13.77	14.5
Edgar's Florida kaolin.....	7.55	6.10	6.40	6.23	7.5
English china clay.....	27.35	24.30	23.70	19.67	14.0
English ball clay.....	17.05	16.20	13.80	14.80	8.0
Harris's N. C. kaolin.....	...	7.10	12.50	...	..
"Hercules" clay.....	...	...	...	15.09	21.0

Trials.—The trials used throughout this investigation were standard 4-inch plates, trade size. 500 were made from each body.

Biscuit Burn.—Eighty plates from each body were biscuit fired to each of the following heat treatments inside the sagger: cone 5, 6, 7, 8, 9 and 10. These six heat-treatments were chosen for two reasons: first because they covered the maximum variation that would likely occur in the most erratic commercial kiln conditions and, second, the extremes were not too far from the field of good commercial practice as not to make the results especially applicable to the general ware industry.

Absorption.—The absorption of each body at the various biscuit burns was determined by soaking three trials from each body from each firing in water for 12 hours, and then boiling for 3 hours. The absorption being calculated in the usual manner from the dry and wet weights. The average of each set of three trials being taken as the absorption value of the series of trials to be used in later tests. These values are given in Table III.

TABLE III

Biscuit heat-treatment		Body				
		A	B	C	D	E
Cone	5.....	13.0%	13.2%	14.2%	12.8%	12.6%
	6.....	10.6	10.5	11.2	10.3	10.4
	7.....	7.9	8.0	9.1	7.6	7.7
	8.....	6.6	6.6	7.4	6.3	6.1
	9.....	4.4	4.5	6.0	4.7	4.5
	10.....	2.1	2.2	3.8	2.7	2.9

Dipping.—For the purpose of identification the cone to which each set of trials was fired was stamped with a cobalt stain on the back of each plate within the group. All trials were soaked in water for 12 hours, wiped off, and dipped in a regular commercial glaze weighing 25 ounces to the pint. The trials were then thoroughly dried before being gloss fired.

Gloss Fire.—A series of six plates from each body from each biscuit burn were gloss fired under the following 12 different heat-treatments:

- a. Cone 1
b. Cone 5

}

18 hrs., periodic kiln, oil fuel.
- c. Cone 1
d. Cone 5

}

24 hrs., periodic kiln, coal fuel.
- e. Cone 1
f. Cone 5

}

30 hrs., periodic kiln, coal fuel.
- g. Cone 1
h. Cone 5

}

40 min. schedule, tunnel kiln, producer gas.
- i. Cone 1
j. Cone 5

}

50 min. schedule, tunnel kiln, producer gas.
- k. Cone 1
l. Cone 5

}

60 min. schedule, tunnel kiln, producer gas.

Test for Crazing and Shivering.—After each trial was marked with its gloss heat-treatment it was set aside for three months. All the trials were then examined for crazing and shivering. The results of this examination at the end of the three months are shown in Fig. 1.

Those trials that showed no glaze defects after standing for three months were tested for crazing according to the standard test already described. The results of these crazing tests are given in Fig. 2.

From a study of the results in Figs. 1 and 2 from observations in several factories where “Hercules” clay is being used in their regular body, we can state without fear of successful contradiction that by the use of 10.0% to 20.0% of “Hercules” clay in the average semi-porcelain body,

the tendency to craze can be greatly decreased under all conditions of biscuit and gloss heat-treatment. In fact it is possible to go from one extreme of crazing to the other extreme, that of shivering, by the simple procedure of substituting increasing amounts of “Hercules” clay in the body.

The data in Fig. 2 plainly shows that there is very little difference in the crazing behavior of bodies “A,” “B,” and “C,” regardless of the fact that body “A” contained 1.89% more flint than body “B” and 2.95% more than body “C.”

Shivering.—It will be noted that body “E” containing 21.0% of “Hercules” clay shivered when subjected to a high biscuit fire and a prolonged gloss fire. From observations during an extensive use of this body we found that if the gloss fire was prolonged over 24 hours this body showed marked tendency to shiver, especially the ware

CONE 5 BISCUIT														
BODY NO.	GLOSS HEAT-TREATMENT												REMARKS	
	a	b	c	d	e	f	g	h	i	j	k	l		
A														
B														
C														
D														
E														
CONE 6 BISCUIT														One trial shivered
A														
B														
C														
D														
E														
CONE 7 BISCUIT														
A														
B														
C														
D														
E														
CONE 8 BISCUIT														
A														
B														
C														
D														
E														
CONE 9 BISCUIT														
A														
B														
C														
D														
E														
CONE 10 BISCUIT														Two trials shivered
A														
B														
C														
D														
E														

Shivered

Crazed

Glaze fit

Shivered Crazed Glaze fit

FIG. 1.

in the first ring which was subjected to the higher temperatures of the gloss fire. Very little shivering occurred in the ware fired in the third ring of the gloss kiln. The ware always cracked or shivered through its weakest point. A piece of ware with a thin section or an air bleb would shiver, while another piece not possessing these structural defects but fired under the same conditions could be made to shiver.

Another interesting feature of this shivering was the failure of the ware soon after being gloss fired. If a piece of ware shivered it invariably did so within three weeks from the time it was drawn from the kiln and no further shivering was induced in the subsequent heating and quenching test.

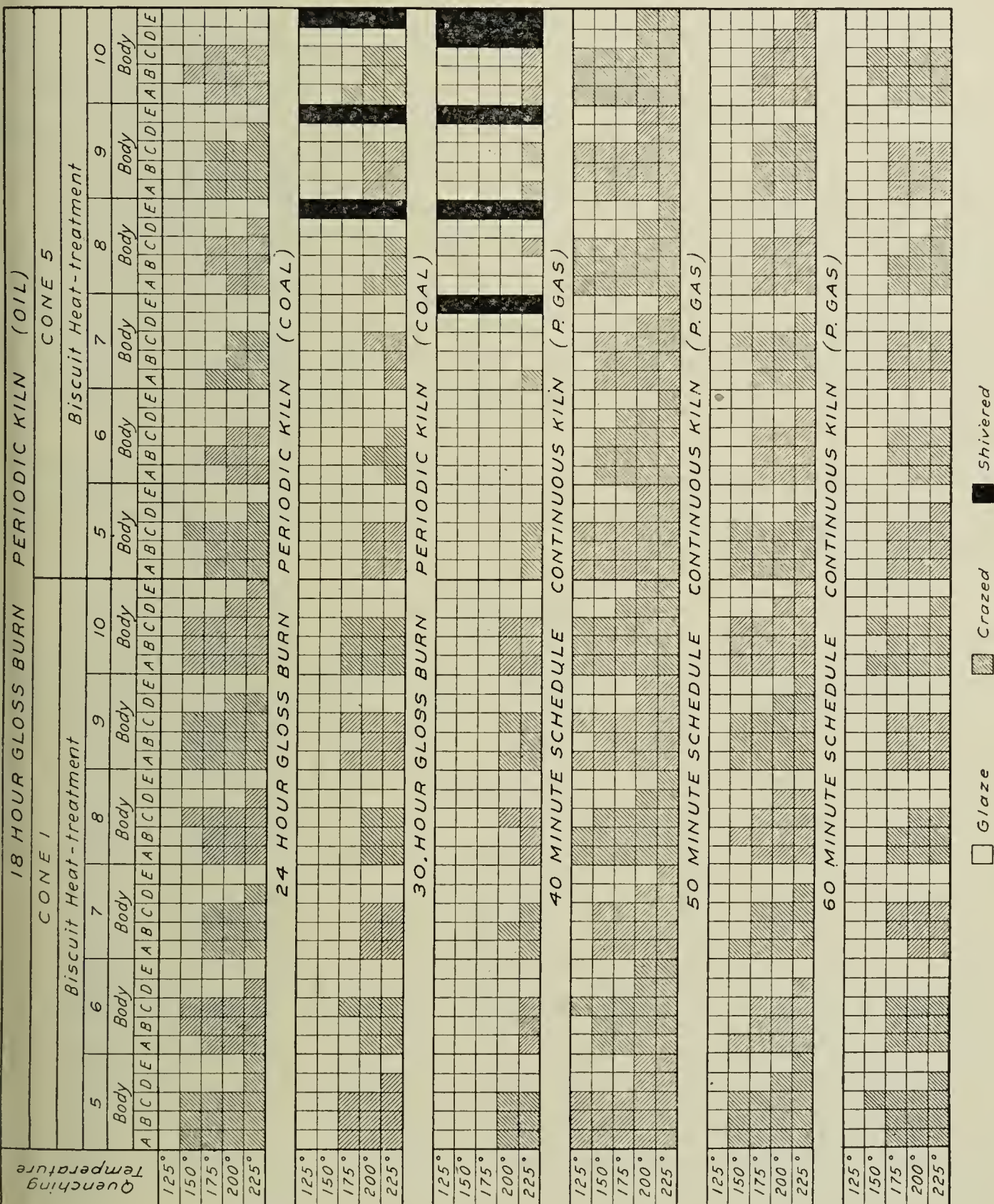


FIG. 2.

A body containing 35.0% of flint and 42.0% of "Hercules" when gloss fired to cone 1 or cone 5 in 17 hours showed no signs of shivering. A 35.0% mixture shivered slightly when gloss fired in 20 hours.

To produce a body free from crazing and shivering we recommend the use of 20.0% of "Hercules" clay when the duration of the gloss burn in a

periodic kiln is less than 18 hours or the schedule of a tunnel kiln is 50 minutes or less. Fifteen per cent of "Hercules" clay should be used when the time of firing a periodic kiln is about 24 hours or the schedule of the tunnel kiln is 60 minutes or more. If the time of firing of the gloss periodic kiln is maintained at about 30 hours the percentage of "Hercules" clay used in the body should not exceed 10.0%

It must be remembered that "Hercules" clay is neither a ball clay nor a china clay, but a cross between these two. It does not have as great a shrinkage as English ball clay, but its shrinkage is more than that of English china clay. "Hercules" clay has a modulus of rupture of 325 pounds per square inch, while our best grade of English ball clays have a transverse strength of about 400 pounds per square inch, and English china clays 20 pounds. The absorption of this clay is less than that of the imported china clays but greater than that of ball clays which vitrify at cone 8 to 9. "Hercules" clay has a fired color far better than the best grade of English ball clay on the market but it is not as white as our best grade of kaolins.

Therefore, it can readily be seen that in order to use this clay to its best advantage it must be substituted for both a portion of the china clay and ball clay in whiteware bodies.

Absorption

The opinion is widely held among potters that the greater the porosity of the body the greater is its tendency to craze. When a potter has trouble from crazing he will invariably increase his biscuit fire, regardless of the cause of the crazing. Often times the ware is fired so hard in the biscuit as to cause a marked increase in the biscuit losses due to an increase in the amount of stuck and warped ware; also the seconds and thirds are increased due to blueware, cut ware, too thin a glaze, or dry edges.

Regardless of the insistence upon the part of nearly every practical potter that there is a direct relation between the porosity of a body and its tendency to craze, it was quite evident from an extensive analysis of factory results that direct relation does not exist. This is borne out by the results in Fig. 2. There can be quite a range in absorption without any appreciable change in crazing behavior, and either an increase or a decrease in absorption beyond certain limits will cause crazing. In other words a body with a low absorption crazes just as quickly as one with a high absorption, all other factors being equal.

Doubtless the average potter formed his opinion regarding the value of increased biscuit fire as a cure for crazing from two different sources. First, it is well known that vitreous china shows very little, if any, tendency to craze. However the practical potter errs when he fails to take into consideration the high flint content (38.0% to 40.0%) of a vitreous china.

body as compared with that of an average semi-porcelain body 30.0% to 34.0%. This increased flint is sufficient in itself to cause the difference in crazing behavior rather than the degree of vitrification. Second, in nearly every case when a potter has had trouble from crazing and has increased his biscuit fire, the tendency of his ware to craze has been decreased. But again in drawing his conclusions he fails to consider a very important factor, the thickness of the glaze coating. With increased biscuit fire and the resulting decreased absorption of the ware, there is always a decrease in the thickness of the glaze which is the direct cause of the decreased crazing noted. In other words the same results are obtained by just dipping the ware thinner as can be secured by an increased biscuit fire, at the same time eliminating the many objectionable features caused from a low absorption, such as warpage, blue ware, cut ware, too thin a glaze, etc., which are as sure to follow in the regular process of manufacture semi-porcelain dinner ware, as night follows the day.

The following investigation was made to verify the above results and to more clearly define the permissible range in absorption.

A number of sets of trials, each consisting of twelve five-inch plates, were biscuited in various sections of a biscuit and gloss kiln and in a porcelain kiln fired to cone 11. The absorption of each set of trials was determined and those selected for this test which possessed the desired porosity. All the selected trials were soaked in water; dipped in a glaze weighing 25.5 ounces to the pint; dried; gloss fired to cone 3 in 24 hours; then tested for crazing. The results are given in Table IV.

TABLE IV

No.	Absorption	Quenching temperature				
		125°C	150°C	175°C	200°C	225°C
1	1.5%	..	Crazed	....	....	..
2	3.0	..	Crazed	....	....	..
3	4.9	..	Crazed	....	....	..
4	5.6	..	....	Crazed	....	..
5	6.6	..	....	Crazed	....	..
6	7.5	..	....	....	Crazed	..
7	8.3	..	....	....	Crazed	..
8	9.5	..	....	....	Crazed	..
9	10.5	..	....	....	Crazed	..
10	11.3	..	....	....	Crazed	..
11	12.6	..	....	....	Crazed	..
12	13.4	..	....	Crazed	....	..
13	14.6	..	Crazed	....	....	..
14	15.3	..	Crazed	....	....	..

A mere cursory examination of the results in Table IV, which have been derived from large commercial tests and not mere laboratory tests, should make it very clear to the most conservative potter that only under certain

conditions would it be advisable to increase the biscuit fire to cure crazing. If the absorption of the ware in the first ring is greater than 7.0% and the ware in the third ring has an absorption greater than 13.0%, then and only then would it be best to increase the biscuit fire. If the absorption of the ware in the third ring exceeds 13.0%, but the first ring ware has an absorption of less than 7.0%, it is simply a case of bad heat-distribution, and there is no cause for increasing the biscuit fire if crazing occurs. However, the method of firing should be given prompt attention and the absorption brought within reasonable limits.

Best results are obtained with an approximate absorption of 7.0% to 12.0%. Either a marked decrease below the 7.0% or an increase beyond the 12.0% would cause an increase in the crazing behavior of the average semi-porcelain body, all other factors being equal.

This gives a permissible variation in absorption of about 5.0% which is ample for good firing conditions in periodic kilns, and can be maintained over long periods of time provided proper methods of control are used.

Time-Temperature of Gloss Burn

Seger and other writers have emphasized the value of increasing the temperatures of the gloss fire as an effective means of curing crazing. However, nearly every semi-porcelain manufacturer regularly fires his ware from cone 1 to cone 4, and oftentimes the ware in the first ring reaches cone 5. This is practically the limit of gloss heat-treatment with the type of bodies that are used today, as any increase beyond cone 5 would cause considerable warpage of the ware in the first ring. Again we see that commercial conditions of manufacture practically eliminate another suggested cure for crazing.

By comparing the crazing behavior of the trials gloss fired to cone 1 with those gloss fired to cone 5 (Fig. 2), we note that in the case of the three periodic kiln burns the plates show a marked decrease in their tendency to craze when fired to the higher temperature but that there was very little difference, if any, between the cone 1 and cone 5 heat-treatment in the three tunnel kiln burns. Why this difference between periodic kiln and tunnel kiln? It is evident that some other factor besides temperature is the direct cause of the decreased crazing when the temperature of the gloss fire in a periodic kiln is raised. The only factor that could enter into the problem would be the time factor. When one analyzes the manner in which the heat is advanced in periodic and tunnel kilns, it becomes very plain that there is a vast difference in the time. In the periodic kiln the time required to go from about cone 05 where the glaze starts to mature to cone 1 is much greater than the time between cone 05 and cone 1. But on the other hand the conditions in the tunnel kiln are vastly different. Here the moving cars are moved through the hot zone at the same rate with the

top at about cone 5 and the bottom at cone 1, the ware on the top of the car being fired to cone 5 in approximately the same maturing time as the ware on the bottom of the car is fired to cone 1.

This brings us to the consideration of one of the most important factors affecting crazing: the *time factor*, or the length of the gloss burn; but one that has very seldom, if ever, been considered to any great extent by the practical potter.

The effect of time on crazing is very plainly shown by the data in Fig. 2. From a study of these results it becomes perfectly evident that by increasing the time of firing a gloss kiln by six hours or more, within the practical limits of 18 to 30 hours, a very decided decrease in crazing occurs. The fact is irrefutable that in the time factor the potter has a very good means of decreasing crazing.

There is no assumption in saying that upon the occurrence of crazing, the first and best thing to do is to increase the time of firing the gloss kiln, to less than 30 hours. Such a procedure is by far the most logical thing to do regardless of the direct cause of the crazing, because it supplies an immediate remedy, so necessary in a pottery, if large losses are to be avoided. It produces a temporary relief without decreasing the output to any marked degree, or causing other losses such as warpage, dry edges, etc. It does not interfere with the orderly processes of manufacture, and affords the manufacturer ample time to investigate the direct cause of the trouble.

It must be borne in mind that when the length of the gloss burn is increased the extra time should be consumed chiefly in the latter portion of the burn, as is the general practice. It is possible to increase the time of firing a periodic gloss kiln without decreasing the crazing, by using all the extra time during the fore part of the burn. In other words it is the maturing time of the glaze (cone 05 up) that must be increased if crazing is to be decreased by increasing the length of the gloss burn.

The use of oil as a fuel in gloss kilns together with a decrease in firing time; the tunnel kiln with its short hot zone; and the general demand for more speed in manufacture, have been the paramount causes of the continued crazing of American dinner ware.

There is no doubt but that fuel oil firing of periodic gloss kilns, and the tunnel kilns, regardless of the short maturing time allowed the glaze, have many advantages which are meeting with favor among the potters. Therefore, in order to meet these new conditions and the demand for speed, it becomes necessary to make changes in the body composition. The only change that we have found which would meet all the practical conditions of manufacture and at the same time decrease the tendency to craze, is the substitution of "Hercules" clay for a portion of the English ball and English china clay in the regular semi-porcelain body. A "Hercules"

clay body is not only free from crazing but it has a much greater strength in the clay state with the resulting decreased biscuit losses.¹

Acknowledgment.—The writer wishes to acknowledge his indebtedness to C. L. Sebring, President, Sebring Pottery Co., for many timely suggestions and assistance throughout the entire investigation. It was only Mr. Sebring's progressive principles that made it possible to bring this investigation to its successful conclusion.

We also wish to express our appreciation of the assistance of Donald Allbright, Asst. Manager, Limoges China Co.; Harry McMasters, Gen. Supt., Sebring Pottery Co.; and Raymond Green, Supt., Gem Clay Forming Co.

SEBRING POTTERY COMPANY
SEBRING, OHIO

¹ *Jour. Amer. Ceram. Soc.*, 5 [9], 588 (1922).

DEFORMATION STUDIES OF SILICATES AND ALUMINUM SILICATES OF THE ALKALIES

BY BRYAN A. RICE¹

ABSTRACT

The following investigation includes studies of the two ternary systems $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ and $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$.

In each system two areas of low fusibility were found; one including members high in alkali, low in silica, and low in alumina; the other including those high in silica, low in alkali, and low in alumina. In both systems the high silica area was the one studied in detail as being of more practical ceramic value.

On each triaxial three eutectics (two binary and one ternary) were established. They had the following compositions:

Per cent	Molecular	Appr. def.
$\text{K}_2\text{O} - \text{Al}_2\text{O}_3 - \text{SiO}_2$	$\text{K}_2\text{O} - \text{Al}_2\text{O}_3 - \text{SiO}_2$	°C
55.0 45.0	1.00 1.291	780
17.5 82.5	1.00 7.43	880
17.4 - 5.2 - 77.4	1.00 - 0.276 - 6.978	870
$\text{Na}_2\text{O} - \text{Al}_2\text{O}_3 - \text{SiO}_2$	$\text{Na}_2\text{O} - \text{Al}_2\text{O}_3 - \text{SiO}_2$	
51.5 48.5	1.00 0.972	830
18.4 81.6	1.00 4.579	860
17.5 - 5.4 - 77.1	1.00 - 0.185 - 4.55	800

The terms "eutectic" and "deformation eutectic" are used in this paper to designate those compositions which require the lowest temperature to complete deformation when uniformly heated with other compositions in the manner outlined in the following studies. Deformation was judged by the same method used with standard pyrometric analyses.

Introduction

The Geophysical Laboratory, Carnegie Institute of Washington, Washington, D. C., has done some very careful and accurate work on the following ternary systems:

$\text{CaO}-\text{Al}_2\text{O}_3-\text{SiO}_2$	(<i>Jour. Amer. Chem. Soc.</i> , 38 , 568 (1916)).
$\text{MgO}-\text{Al}_2\text{O}_3-\text{SiO}_2$	(<i>Am. J. Sci.</i> , 45 , 301 (1918)).
$\text{CaO}-\text{Al}_2\text{O}_3-\text{MgO}$	(<i>Jour. Amer. Chem. Soc.</i> , 6 (1916)).
$\text{CaO}-\text{SiO}_2-\text{MgO}$	(<i>Am. J. Sci.</i> , 46 , 48-81 (1919)).

A. S. Watts² has published results on $\text{MgO}-\text{Al}_2\text{O}_3-\text{SiO}_2$ system, and also on the ternary system $\text{BaO}-\text{Al}_2\text{O}_3-\text{SiO}_2$. However, to the best of the writer's knowledge, no data is available dealing with the thermal behavior of K_2O and Na_2O as oxides in combination with SiO_2 or Al_2O_3 and SiO_2 . Some data on the straight line $\text{K}_2\text{O}-\text{SiO}_2$ is available in "Ternary System $\text{H}_2\text{O}-\text{K}_2\text{SiO}_3-\text{SiO}_2$."³ C. J. Peddle in his article "The Development of Various Types

¹ Presented as a thesis for the Degree of Master of Science at Ohio State University. Received Nov. 28, 1922.

² *Trans. Amer. Ceram. Soc.*, **19**, 457 (1917).

³ Morey and Fenner, *Jour. Amer. Chem. Soc.*, **39** [6], 1173 (1917).

of Glass,"¹ includes K_2O-SiO_2 and Na_2O-SiO_2 glasses but his study is confined almost totally to solubilities and refractive indices and very little is said regarding temperature. Therefore the following investigation of the silicates and aluminum silicates of the alkalis was undertaken in an attempt to provide the ceramist with data which would prove of value in analysis or synthesis of glasses, glazes and enamels.

The method of study was to make up cones of varying composition and observe their deformation behavior when heated. Where possible, the actual raw materials were used, it being thought advisable to study them in this form and later, if time permitted, to fuse each member, pulverize, make into cones, and take deformation observations on these fritted mixtures. Commercial raw materials were used rather than chemically pure because we were after practical results which could be applied commercially.

The same general rate of heating was maintained as nearly as possible for each burn. It was found by trial that as much as one or even two hour difference in total time of heating did not affect their order of deformation although the final temperature might vary. Observation was confined to order of deformation in establishing the eutectic and, although temperatures were recorded for each burn, it was not considered vital to attempt to measure accurately the temperature of deformation of the eutectic. At all times great care was taken to insure uniform heat throughout the furnace.

It is realized that to really complete the work started, data other than that of deformation should be secured such as solubility studies, refractive indices, degree of reaction of one constituent with another, and possible mineral formations which might take place. It is hoped that it will be possible to make such determinations in the future investigations of which this is merely the beginning.

All members on any of the triaxials shown in the following studies are given in per cent by weight.

Series I. $K_2O-Al_2O_3-SiO_2$

For this purpose it was desired to use as far as possible the simple oxides Al_2O_3 and SiO_2 were easily procurable in that state. However, it was necessary to add K_2O as a simple salt. K_2CO_3 and KNO_3 are commercial methods of accomplishing this.

It was decided to use K_2CO_3 . On attempting to make up cones from the raw materials, difficulty was encountered in using this material owing to its extreme deliquescence when pulverized. The batch could be mixed up to the proper consistency but, before cones could be made, it would set so hard that it could not be worked.

¹ *Jour. Soc. Glass Tech.*, 4, 1-107 (1921).

This fact caused us to change to KNO_3 which was much better. Using dextrin as a binder, the cones were made up in the standard size and shape of Orton's pyrometric cones.

First Burn (Series I).¹—Referring to the article by Morey and Fenner on "The Ternary System $\text{H}_2\text{O}-\text{K}_2\text{SiO}_3-\text{SiO}_2$,"² it was decided that some of the cones would go down at a temperature below red heat. This would necessitate some outside source of light. For this purpose a small electric furnace was used. A platinum-platinum rhodium thermocouple was inserted in the back of the furnace. The front of the furnace was built

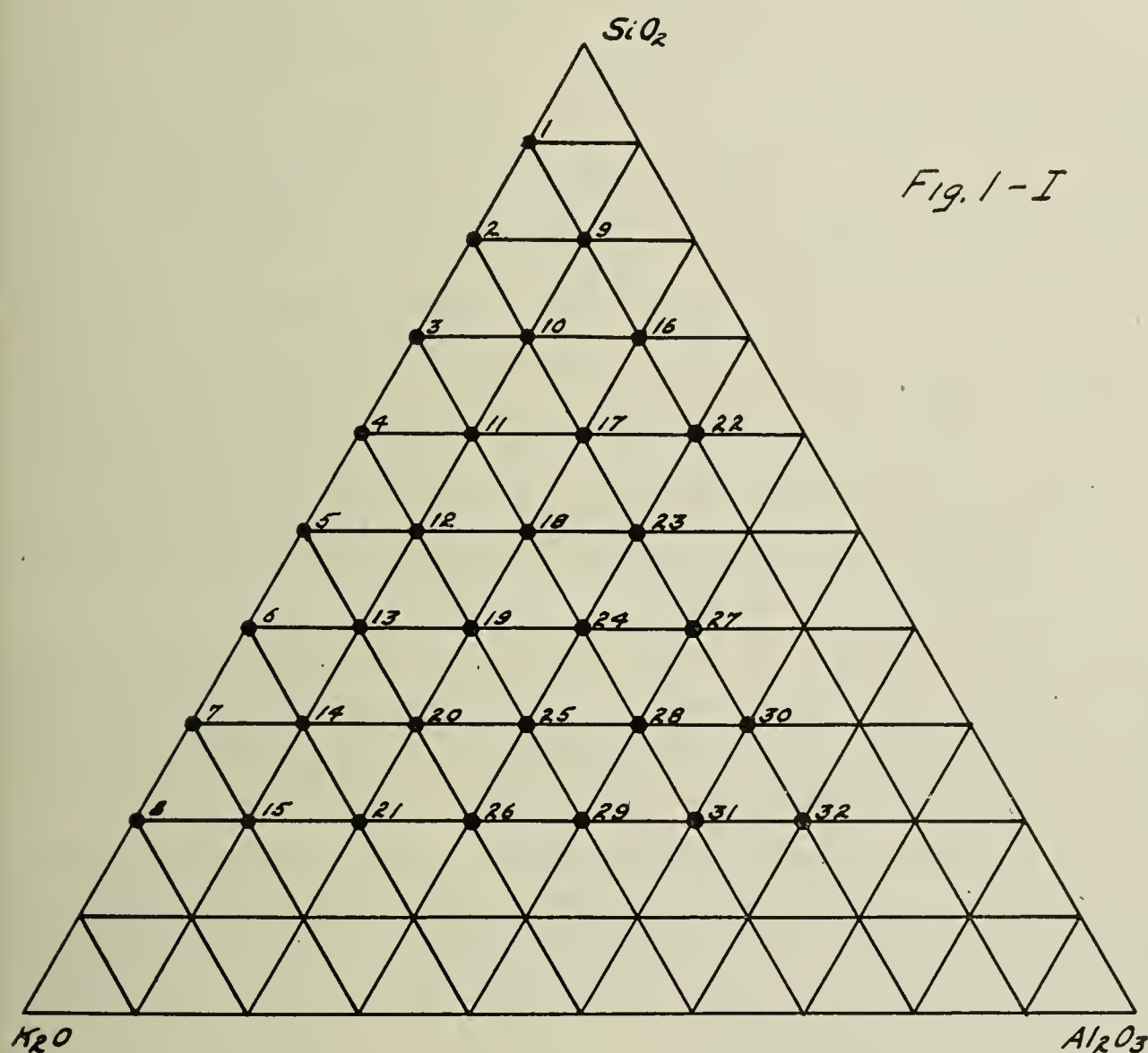


Fig. 1-I

up so that an electric light outside would illuminate the cones and they could be observed through a small peep hole also in the front.

The first burn consisted of members 1 to 8 on the straight line series between K_2O and SiO_2 . (Fig. 1-I.) The cones were placed in the furnace and heated slowly requiring $8\frac{1}{2}$ hours to heat from room temperature to 670°C . At this temperature all cones were down but 1, 2, 3 and 4. These showed no signs of deformation, except the very tip of 4. The remaining cones had not deformed in the regular way but seemed to fall apart or slump down.

¹ October 22, 1919.

² *Loc. cit.*

In fact there was much doubt whether there was any action between the KNO_3 and SiO_2 at all. It seemed more probable that the KNO_3 burned out leaving the SiO_2 behind in its original state. If true, those cones containing a large quantity of KNO_3 did not have sufficient SiO_2 left to hold its shape and simply crumbled down while those higher in SiO_2 maintained original positions. Cone 5, which was a 50-50 mixture, seemed to do a little of both.

At any rate it seemed evident that either of two things happens:

1. KNO_3 volatilizes before it can act on SiO_2 .
2. Rate of heating is too fast to allow action to take place.

Another burn was made heating up at a slower rate.

Second Burn—(Series I).—For this burn cones 3, 4, and complete triaxial 5-8-26 (Fig. 1-I) were used. This included all members which had gone down in Burn 1. The temperature was raised more quickly in this burn requiring only 8 hours to reach 1100°C .

Again 3 and 4 did not go down. The remaining cones behaved in the same manner as those which deformed in Burn No. 1.

Upon observing cones 1, 2, 3 and 4 of this burn and also the previous one it was noted that they had a porous structure when taken from furnace. This porosity increased with increasing KNO_3 in original cone mix. This serves to strengthen the theory that volatilization took place too quickly for the KNO_3 and SiO_2 to react.

Third Burn—(Series I).—The method of burning was changed as follows. The furnace was brought to 1050°C and held at this temperature while the cones were placed in the furnace and then order of deformation noted. All members in Fig. 1-I were used.

All cones went down under this treatment. The reaction was very rapid and violent. The higher SiO_2 members showed a more nearly normal deformation but all cones were bloated and bubbly. The extreme rapidity of reaction indicated that this temperature was too high for results that could be graded and classified.

Fourth Burn—(Series I).—This was conducted the same as Burn No. 3, but the furnace temperature was 850°C . Several cones, high in Al_2O_3 and SiO_2 , did not deform.

In the various cones which remained standing the same condition was observed as in the Burns 1 and 2 in which the temperature was gradually raised. The condition to which it referred was attributed to volatilization. Subsequent examination with the aid of the microscope showed that it was more probable that the KNO_3 , owing to its extremely low melting point, flowed away without reacting with the SiO_2 and Al_2O_3 leaving these behind in their natural state. The cone plaques in which they were placed showed evidence of absorbing this extremely fluid KNO_3 .

Smelting Members.—From the foregoing it was evident that the melting point of KNO_3 (337°C) was entirely too low to give results with cones made up from the raw materials. Hence it was decided to try smelting the batch and then make up cones from the resultant frit.

A batch totaling 100 grams of member No. 8 was placed in a large porcelain crucible. This was heated in a furnace, the source of heat being a Meeker blast burner. With this quite a high temperature could be obtained.

Here again trouble was encountered. The KNO_3 would melt down rapidly but was extremely slow in taking SiO_2 into solution. Through the liquid KNO_3 was a honey comb mass which seemed to melt with great difficulty and was too viscous to remove from the crucible. Also, temperature control to prevent frothing over was difficult.

After several trials with no better results even at high temperatures, K_2CO_3 was substituted for the KNO_3 . This seemed to work much better. The probable reasons were its more alkaline nature and its higher melting point (909°C) which approaches that of K_2SiO_3 .

The first trial produced a clear, highly deliquescent glass. The sample was marked 8-A. There was considerable irregularity connected with this trial. It was allowed to heat too long and had practically eaten through the crucible. The fact that it probably dissolved considerable SiO_2 and some Al_2O_3 in so doing seems to account for its clearness. Under the microscope it showed all glass. Analysis showed 32.26% SiO_2 and 7.5% Al_2O_3 .

The next trial, marked 8-B, was more closely watched and the moment a clear solution was obtained the melt was poured. The method of chilling in all cases was to pour into water-jacketed pan. Analysis showed: 4.84% SiO_2 ; 4.26% Al_2O_3 .

It was then attempted to prepare some K_2SiO_3 in order to study its properties under the microscope. For this purpose a platinum dish with a porcelain cover was substituted for the porcelain crucible. A mixture of K_2CO_3 and flint (both commercial) totaling 43 grams raw mix and proportioned to give theoretical K_2SiO_3 , was placed in the dish and heated till a clear quiet fusion was obtained. This was chilled as above.

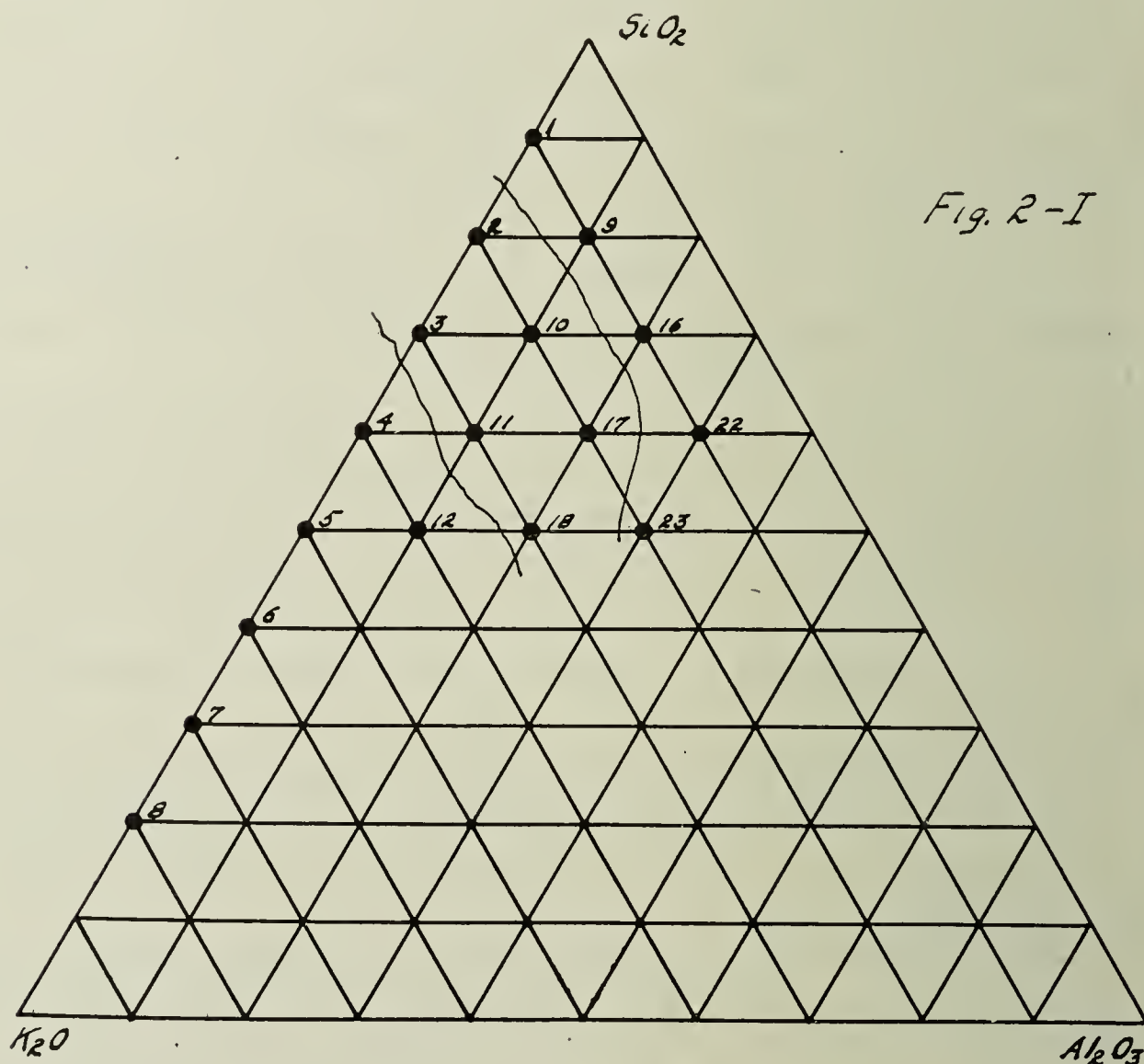
That portion of the melt next to the pan which cooled quickly resulted in a transparent glass with a slight greenish tint while that which cooled more slowly crystallized forming a cloudy white mass. Under a magnifying lens rather large fibrous crystals could be seen. Under the microscope the crystallized portion showed fibrous crystals, probably orthorhombic, with parallel extinction. Index of refraction was about 1.51 to 1.52 approximately the same as the glass. Interference figure showed emergence of an acute negative bisectrix. When a drop of water was placed upon the crystals under the microscope they did not dissolve uniformly but broke

up into shred-like forms probably along cleavage planes. From Fenner's description (the ternary system $\text{H}_2\text{O}-\text{K}_2\text{SiO}_3-\text{SiO}_2$) these crystals were identified as the disilicate $\text{K}_2\text{O} \cdot 2\text{SiO}_2$.

A second melt showed the same results as the first.

This would indicate quite a bit of volatilization of K_2O .

From the above it seemed advisable to smelt the members in a platinum dish to prevent contamination from dissolved SiO_2 and Al_2O_3 and afterwards to analyze the melts to obtain the proper positions on the triaxial diagram.



Members 5, 6, 7 and 8 smelted with comparative ease but those with increased SiO_2 content above that of 5 required an almost prohibitive temperature. Member 4 was smelted at the full temperature of the Meeke blast lamp before a fusion was obtained, while those higher in SiO_2 were not obtained in fused state. The addition of Al_2O_3 , even to those high in K_2O , produced a fusion too viscous to pour from the platinum dish.

The above difficulties seemed to make it less trouble to make up cones from raw materials using K_2CO_3 . A preliminary burn in a small electric furnace on the high K_2O members was made to see if a regular deformation would take place instead of results as obtained with cones made from KNO_3 . This burn showed a quite uniform deformation.

Consequently it was decided to use K_2CO_3 , the analysis of which was 57.4% K_2O . Results from the $Na_2O-Al_2O_3-SiO_2$ series which was started using Na_2CO_3 showed it impractical for our purpose to investigate the high K_2O area. This will be discussed later. However, for the first burn we did include some high K_2O members on the straight line K_2O-SiO_2 . (Fig. 2-I.)

Fifth Burn—(Series I).—Started 3:45 P. M.¹

Time	M. V.	Temp. °C	Remarks
4:15	7.6	495	
4:20	8.75	585	
4:30	9.5	660	
4:45	10.4	720	6, 5, 7 and 2 started
4:50	10.6	740	8 started
4:52	11.0	770	12 tipped backwards slightly
4:55	11.25	795	7, 6 and 8 down—4 started
5:00	11.4	805	2 down
5:20	12.0	860	
5:25	12.5	900	3 down—10 and 11 started
5:30	12.6	905	11 down followed by 10
5:33	12.6	905	Heat turned off

Starting order.....	6	5-7	2	8	4	3	11	10	9
Final deformation.....	7	6	8	2	3	11	10		

7, 6 and 8 were very fusible and, due to excessive alkali content, were almost totally absorbed by the cone plaque. They seemed to be merely $K_2SiO_3 + K_2CO_3$ and took up moisture from the air to such an extent as to make them soft and gummy like water glass. They did not have the stony, slag-like appearance such as was noted in the Na_2CO_3 series but were rather clear fusions. While realizing the importance of further study in this field before the ternary system $K_2O-Al_2O_3-SiO_2$ could be considered complete, it did not seem practical to spend time to do so at present, because their extreme solubility would seem to unfit them for any valuable use in enamels. Hence, completion of study of this area was deferred and the upper area of low fusibility was considered in the work immediately following. However, there seems to be a straight line eutectic between members 6 and 7 which, when corrected according to analysis of K_2CO_3 will have composition 55% K_2O and 45% SiO_2 or in molecular formula, $K_2O-1.291, SiO_2$ at 780°C. Geophysical Laboratories found a eutectic at $K_2O-1.35, SiO_2$ (775°C).²

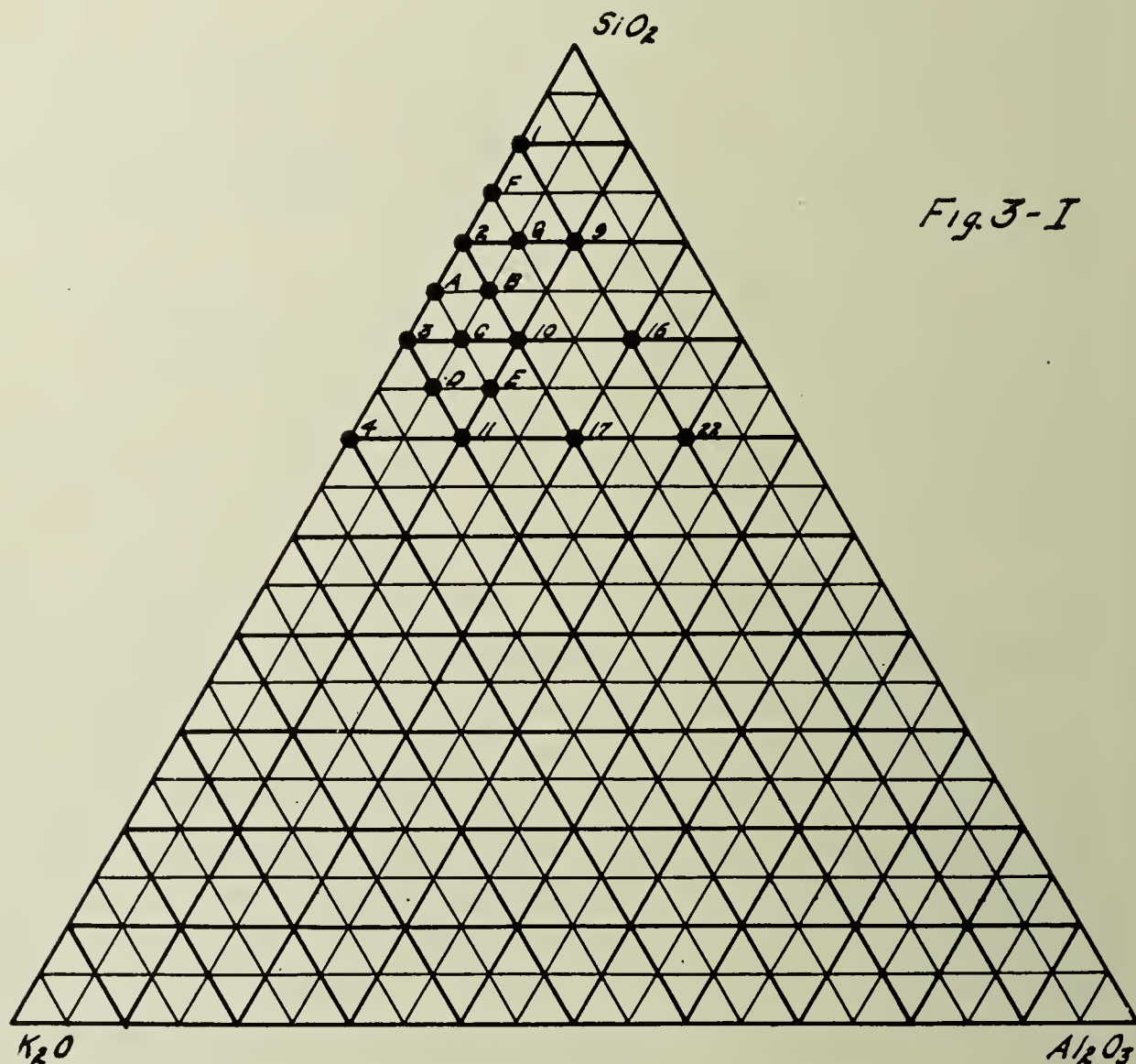
Member No. 2 started first and final deformation was reached first of the cones in this upper area. No. 3, while starting later, deformed very quickly and developed extremely low viscosity. From this standpoint,

¹ March 24, 1920.
² Morey & Fenner, $H_2O-K_2SiO_4-SiO_2$, *loc. cit.*

it was easily the most fusible member in the area. Of the cones which reached final deformation No. 11 was next, followed by No. 10.

There seemed to be quite a range in time and temperature between the final deformation of No. 2 and final deformation or even starting of 3, 10 and 11.

Upon standing for a while, all cones except 1, 2, 9, 16 and 22 showed surface coating probably due to absorption of moisture from the air which brought the soluble salts to the surface where they crystallized. A very slight trace was noticed on No. 2. This was explained as due to the fact



that No. 2 is very close to the eutectic and a state of equilibrium was reached. Those members higher in K_2O would have an excess of K_2O over and above the eutectic mixture which would allow the above described solution and subsequent crystallization. Those members higher in SiO_2 and Al_2O_3 would use up all the K_2O in the eutectic mixture and the excess would be insoluble SiO_2 and Al_2O_3 .

Sixth Burn (Series I).—This included only members 2, 10, 17, 3, and 18 (Fig. 2-I) which included the softer members from Burn No. Started 2:30 P. M.

Time	M. V.	Temp. °C	Remarks
3:30	7.5	480	
3:45	9.1	620	
4:05	10.2	705	
4:30	11.6	820	
4:40	12.0	855	2 started
4:50	12.4	890	3 started
4:55	12.5	900	2 down
5:10	13.0	940	11 started
5:15	13.1	945	
5:20	13.25	955	3 down—10 started—11 down
5:35	13.6	985	
5:55	14.0	1020	10 down. Temperature practically constant for last 5 minutes—current shut off.
Starting.....	2	11	3 10
Down.....	2	3	11 10

This was a very good check. The relative behavior of the cones was much the same, particularly was this true of 2 and 3. This establishes No. 2 as the eutectic (deformation) of this area within 10% limits. No. 3 again showed decidedly the least viscosity after the cone once started.

Seventh Burn (Series I).—In this burn the limits were brought down to 5%, members 2, A, 3, B, C, D, 10, E and 11 being used. (Fig. 3-I). Started 9:15 A. M.

Time	M. V.	Temp. °C	Remarks
11:00	8.0	520	
11:35	10.5	730	
12:00	11.8	840	2 and B started
12:05	12.0	855	
12:10	12.2	870	A started—B down
12:13	12.3	880	A tipped over and is touching tip of 2. They are going down together
12:15	12.4	890	2 and A down
12:20	12.5	900	D started—E tipped backwards
12:25	12.6	905	D down
12:31	12.85	920	C started
12:35	12.95	935	C down
12:38	12.97	940	3 started
12:40	13.15	950	3 down—E down backwards

Removed from furnace—replaced in furnace 12 M. V. and temperature brought back up to 13.2 to see effect on viscosity. Removed from furnace again.

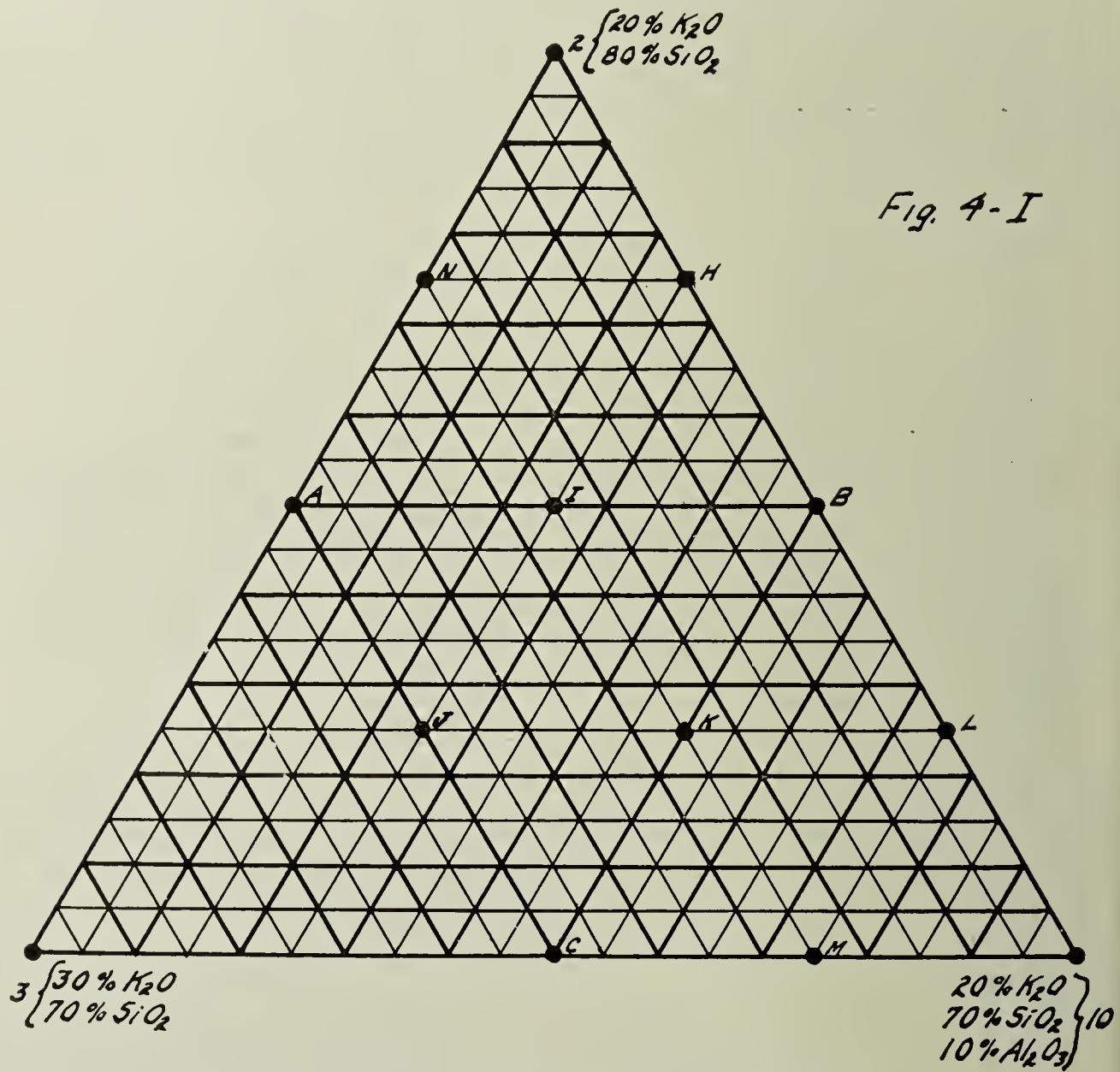
Started.....	2	B	A	D	E	C	3
Down.....	B	2-A	D	C	3-E		

Eighth Burn (Series I).—This burn was principally a check on No. 7. Members F and G were added and 10, E and 11 dropped as these last showed no signs of deformation in Burn No. 7. (Fig. 3-I.) Started 10:00 A. M.

Time	M. V.	Temp. °C	Remarks—Using Bureau of Mines thermocouple
11:30	5.5	640	
12:15	7.4	820	
12:30	7.7	845	B started
12:35	7.8	855	C started
12:40	8.0	870	2 started
12:44	8.1	880	B down first followed by 2
12:47	8.2-	890	C down
12:53	8.4	910	A started
12:57	8.5	915	A down—3 and G started
1:00	8.55	920	3 down
1:07	8.65	930	
1:10	8.75	940	D down

Started.....	B	C	2	A	3	G	D
Down.....	B	2	C	A	3	D	

The manner in which B deformed indicated that it was farther ahead of 2 than the data shows as far as deformation is concerned. In this burn showed slightly less viscosity than A. C went down sooner than previous



B—Eutectic—20.00% K₂O—5.00% Al₂O₃—75.00% SiO₂.
B—Corrected—17.41% K₂O—5.16% Al₂O₃—77.43% SiO₂.
B—Molecular Formula—K₂O—0.276 Al₂O₃—6.978 SiO₂.

but more nearly in the order one would expect. Considering B as nearer the deformation eutectic than any of the rest, the order of deformation was practically what would be expected with the possible exception that the position of 3 and D should be reversed.

As noted, G started to deform but did not proceed very far. No evidence of deformation of F was observed.

B can be considered as the deformation eutectic within limits of 5%. Member 2 is a deformation eutectic between K_2O and SiO_2 within 5% limits. Its composition as corrected from analysis of the K_2CO_3 used is 7.5% K_2O -82.5% SiO_2 (molecular formula K_2O -7.43 SiO_2), 880°C. This does not check the figures from Geophysical Laboratories which were, 11% molecular formula K_2O -4.0 SiO_2 , 525°C.

Ninth Burn (Series I). (2.5% limits).—Limits were brought down to 2.5%. Members 2, H, B, L, I, C and K were used. (Fig. 4-I.) Started 8:30 P. M.

Time	M. V.	Temp.°C	Remarks
2:15	7.5	480	
2:45	9.8	670	
3:15	11.4	805	
3:25	11.6	820	2 started
3:30	12.0	855	
3:35	12.2	870	2 down—C started
3:45	12.4	890	C down—K started
3:42	12.5	900	H started
3:53	12.6	905	K down—I and B started
3:56	12.65	910	H down—I down—B down
4:00	12.75	915	Heat shut off.

This burn did not check previous results in that 2 was down ahead of B while in both Burn No. 7 and Burn No. 8 the positions were reversed.

Tenth Burn (Series I).—Check on Burn No. 9. Started 8:30 A. M.

Time	M. V.	Temp.°C	Remarks
9:25	8.2	540	
9:50	9.8	670	
10:00	10.5	730	
10:15	11.2	790	
10:25	11.55	810	2 started
10:35	11.8	840	2 down
10:37	11.95	850	C started
10:50	12.3	880	C down—K, B and I started
10:52	12.4	890	H started—K down
10:55	12.6	905	H down—I down

In this one also 2 was down ahead of B.

To attempt to check this inconsistency cones of 2 and B, made up at different times, were mounted. There were 3 of each and were marked . — 2.. — 2... and B. — B.. — B...

Eleventh Burn (Series I).—Started 8:30 A. M.

Time	M. V.	Temp. °C	Remarks
9:50	8.0	530	
10:15	9.85	680	Tip of 2.. started backwards 2.. started
10:43	11.2	790	B... started
10:49	11.4	805	B... down—B. started 2. started backwards
10:58	11.6	820	2... started—2.. started forward B.. started
11:04	12.0	855	2.. down
11:15	12.3	880	
11:22	12.5	900	B. down—B. . down
11:30	12.8	920	2. down

B... was down ahead of 2... B. was down ahead of 2., but 2.. was down ahead of B.. — 2.. and B.. were from the same lot as gave the inconsistent results in Burns No. 9 and No. 10.

Twelfth Burn (Series I).—This was made as a check on 2... and B.. introducing member H also. Started 2:15 P. M.

Time	M. V.	Temp. °C	Remarks
3:10	7.8	510	
3:45	10.4	725	
3:55	11.0	770	
4:15	12.0	855	B started
4:23	12.2	870	2 started
4:27	12.3	880	
4:30	12.4	890	B down
4:33	12.5	900	2 down—H not started
4:50	13.0	935	H started

Thirteenth Burn (Series I).—As a final check new cones were made of 2, B and H. Started 9:05 A. M.

Time	M. V.	Temp. °C	Remarks
10:40	9.4	640	
10:50	10.0	690	
11:03	10.8	760	B started
11:15	11.25	790	
11:35	12.2	870	B down—2 and H started
11:38	12.3	880	2 down—H started
11:39	12.3	880	H down

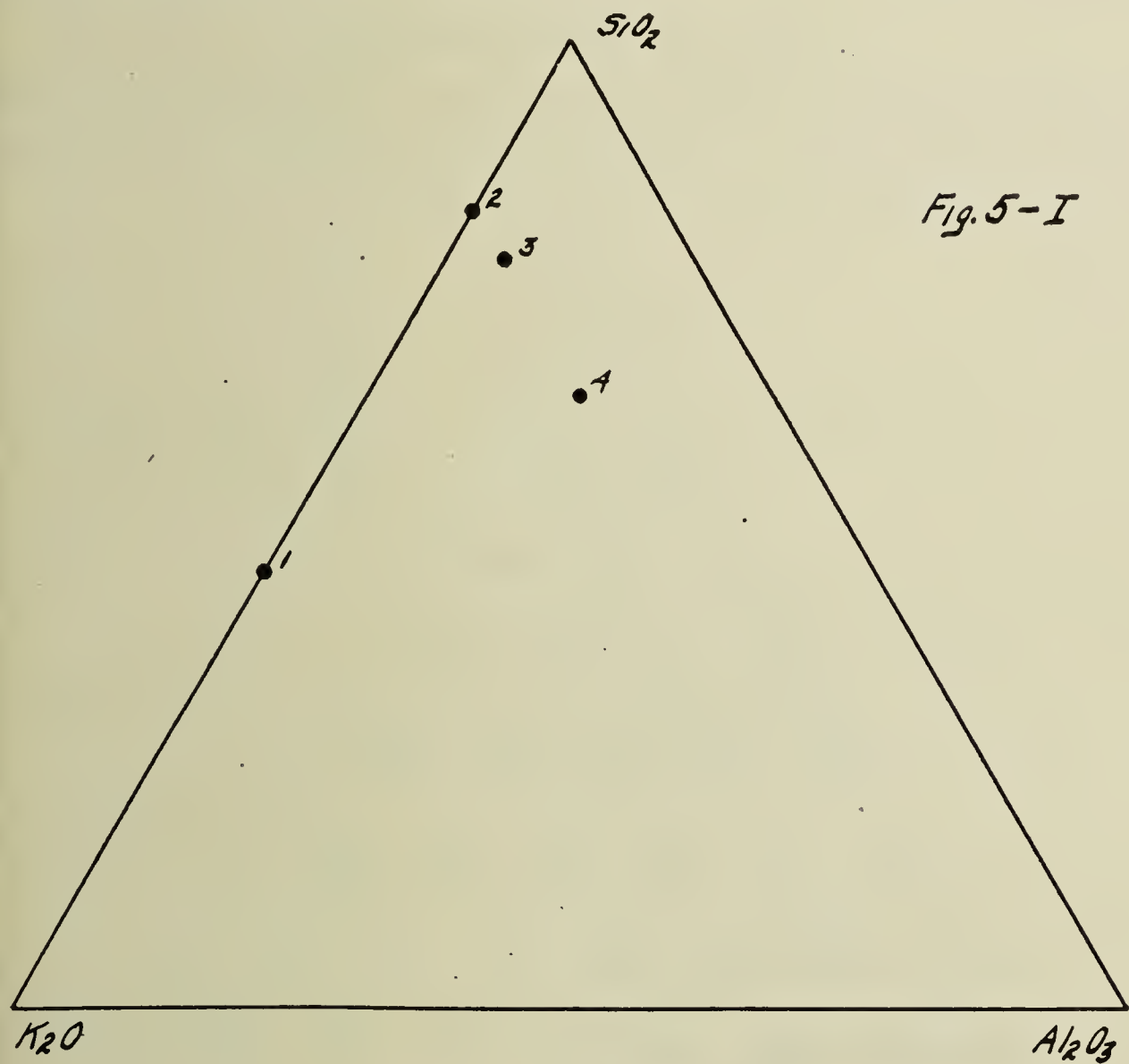
B again was ahead of 2 and H was last.

This seems to establish B as the deformation eutectic within limits of 2.5%, but as in the Na₂O-Al₂O₃-SiO₂ series it must be realized that the deformation points of these last few members lie very close together.

The composition of B from the triaxial is 20% K₂O, 5% Al₂O₃, 75% SiO₂. However, analysis of the K₂CO₃ used showed 17.41% K₂O, 5.16% Al₂O₃, 77.43% SiO₂ or molecular formula K₂O-0.276, Al₂O₃-6.978, SiO₂ (870°C).

Conclusions

1. The members toward the high K₂O end of the triaxial were very deliquescent starting somewhere between members 5 and 6. They became very soft and gummy on standing a short time.



		Limits	Composition						Appr. def., °C
			Per cent			Molecular			
			K ₂ O	Al ₂ O ₃	SiO ₂	K ₂ O	Al ₂ O ₃	SiO ₂	
1	Binary Eutectic	10%	55.0	..	45.0	1.00	..	1.291	780
2	“ “	5%	17.5	..	82.5	1.00	..	7.43	880
3	Ternary “	2½%	17.41	5.16	77.43	1.00	0.276	6.978	870
4	Pure Potash Spar		16.90	18.36	64.74	1.00	1.00	6.00	1350

2. Two deformation eutectics were noted on the straight line between K₂O and SiO₂.

- (a) 55% K₂O
45 SiO₂
(780°C)
- (b) 17.5% K₂O
82.5 SiO₂
(870°C)

3. A ternary deformation eutectic was found of the composition:

17.41% K₂O
5.16 Al₂O₃
77.43 SiO₂

4. This ternary eutectic has a much higher SiO_2 content and lower Al_2O_3 content than any natural potassium aluminum silicate mineral known.

5. Deformation temperature is low (870°C) which brings it close to that of a glass or enamel.

Series II. $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$

This series was started while work on the $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ series seemed to indicate the necessity for using the carbonate rather than the nitrate. Sodium carbonate analyzing 42.9% Na_2O was used.

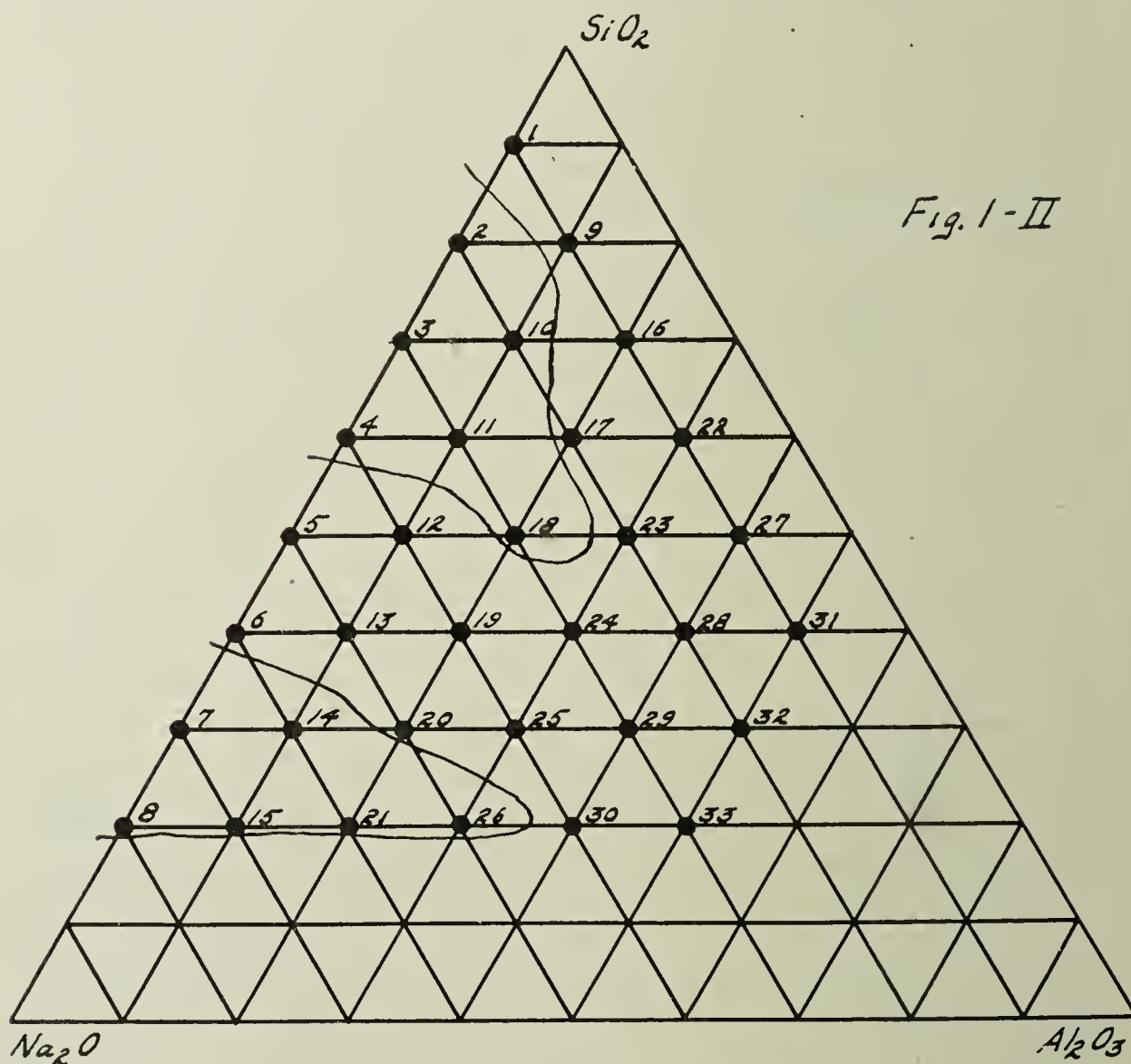


Fig. 1-II

First Burn (Series II).—A series of cones (Fig. 1-II) were then made for the purpose of burning the complete set in one of the large gas fired kilns. A muffle large enough to hold this series was built in the kiln in order to insure oxidizing conditions. Since deformation areas, rather than temperatures, were sought, exact temperature measurements were not made, the order and rate of deformation being more desirable.

A base metal thermocouple was used. Also some Orton pyrometric cones were placed in the muffle. From the start of the burn it was seen that the muffle would not heat evenly. The top and the back were the hottest. They showed a bright red, almost yellow heat, while the remainder of the muffle was slightly hotter than the bottom or right side. Con-

quently the results obtained were not exact. Some interesting observations may be made on some of the cones which were in the same heat. Tabular data was as follows:

Time	Milli-Volts	Remarks
8:30	8.4	
8:45	12.5	
9:00	15.0	
9:15	17.2	
9:45	20.5	
10:00	22.5	
10:30	24.8	
11:00	26.2	020 started
11:15	28.2	
11:30	29.3	020 down—2, 3 and 6 started
11:45	29.9	13, 8 and 15 started
11:50	30.2	17 started
12:00	30.5	19 started
12:10	31.2	7, 14 and 11 started
12:15	31.8	20, 21 started—8 broken 11 tipped against muffle wall
12:25	..	18 started—3 down
12:30	32.3	10 started—2 down—11 down (?)
12:35	..	29 and 31 started
12:40	..	24 and 12 started
12:45	33.0	4 started
1:00	33.9	10 down
1:03	..	15 down—4 broken
1:10	..	23, 28 and 30 started—7 down
1:15	34.5	18 down
1:30	35.0	12 probably down—4 down 015 had started

That the results obtained may be studied to better advantage, it is better to group them as follows:

Order started	Order down
2-3-6	..
8-15	3
17	2
7-4-11	11?
20-21	10
18	7
10	18
24	4
12	12
4	..

Members 13-19-29-31-23-28-30 which are listed in the preceding data having started were found to have merely deformed, some through shrinkage when cones were studied after being withdrawn from the kiln. At this

time also it was discovered that No. 26 had started to deform but was not observed in the kiln due to the fact that it had broken. As noted before when No. 11 started to deform it tipped over and touched the wall of the muffle, thus making the order in which it finally went down a matter of doubt. Study of the cones after withdrawing from the kiln indicated that this member was the most fusible and probably would have been the first to go down had it not been retarded by touching the wall.

While this burn was rather unsatisfactory due to the uneven heat distribution through the muffle, the fact that the majority of the data secured is confined to those cones which were comparatively close together in the high heat zone where the temperature variation was not great makes it worth recording. Therefore, for this burn we will consider only the upper part of the triaxial diagram since those members comprising the lower portion were in the part of the muffle where heat distribution was the poorest.

On the straight line series between soda and silica, members 2-3-4 were the ones which deformed. Of these three, No. 3 was the most fusible. Away from the straight line into the field which also includes alumina we find No. 11 the most fusible followed by 10, 18, 12, 17 and 24 in the order given. The last two members showed only a slight deformation.

To overcome the objections in the above method of heating and to secure more reliable data, this burn was repeated in the electric furnace.

Second Burn (Series II).—The large cones were cut down to a smaller size about $1\frac{1}{2}$ inches in length in order to allow them to be mounted in a more compact manner so that they could be placed in the electric furnace and more uniform heat conditions assured.

RESULTS

Cone 020 was down before 7 M. V. was reached.

9.0 M. V.	610°C	8 started
10.25	710	7, 14 and 15 started
11.6	820	2 and 3 also 4, 11 and 015 started
12.0	855	015 down. 8 probably down but hard to see. 21 and 10 started
12.4	885	11, 15 and 3 down
12.5	895	4 and 7 down. 10 either down or broken
12.6	905	21 down

These results show that two areas of low fusibility exist as shown on the triaxial. The members in the area of the high silica content show a glass condition while those in the lower area where the soda content is higher show more of a slagging condition. Here again member No. 11 seems to show evidence of greatest fusibility; No. 5 is evidently the high point between the two areas. It was hard to observe the order of deformation

ie to so many cones being so closely crowded together. The heat distribution was remarkably good.

The preceding burns, while giving no exact data, have shown two things. First: Two areas of low fusibility exist. Second: One area high in Na_2O does not fuse to a glass but has a stony, slag-like appearance while the area higher in SiO_2 has glassy fusions.

These results were taken as sufficient reason to discontinue further investigation of the high Na_2O field at present and confine our attention to the high SiO_2 area of fusibility.

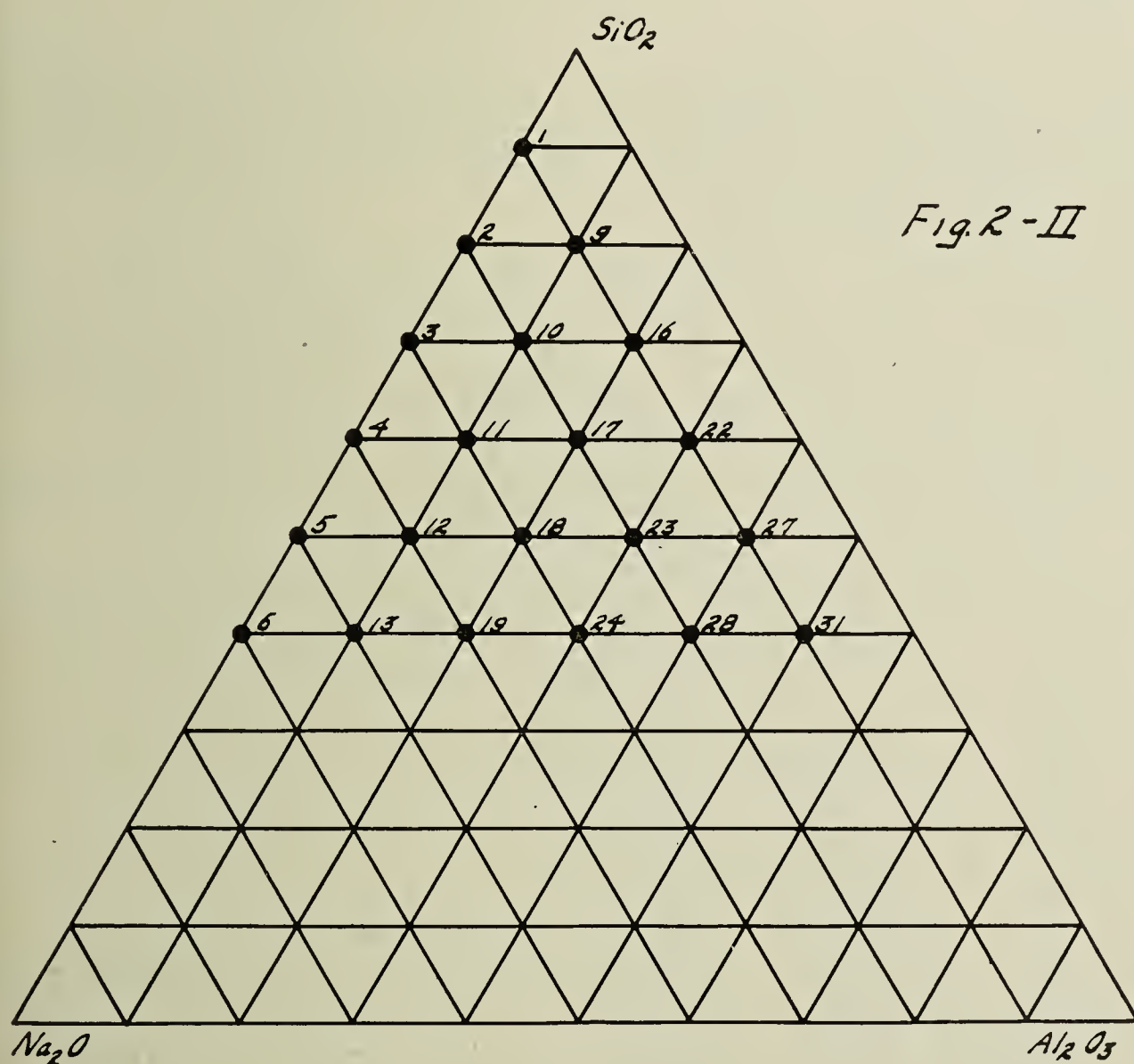


Fig. 2-II

Third Burn (Series II).—The burning was done in the electric muffle furnace which insured even heat distribution. New cones were made. All members of Fig. 2-II were used. Started 9:30.

Time	M. V.	Temp. °C	Remarks
11:00	8.5	570	
11:20	10.0	690	6 started
11:30	10.8	780	11 started
11:35	11.1	790	13 and 2 started
11:40	11.2	795	24 started
11:42	11.3	800	2 down. 10 started

Time	M. V.	Temp. °C	Remarks
11:45	11.4	805	11 down (3 started (?) hard to see 3 has tipped over on 10 and they are going down together—4 started
11:48	11.55	820	10 and 3 down together—17 has gone down previously—just missed it May have mistaken it for 11 but both are down—18 started.
11:54	11.7	830	4 down
11:55	11.8	840	18 down
Started.....	6	11 13-2	24 10 18
Down.....		2 11	10-3 4 18

Cones 1, 9 and 16 did not deform at all but had a vitreous glossy appearance very similar to those that did deform. On observation three weeks later all had a dull surface probably due to atmospheric action on the soluble compounds.

The large number of cones under observation made it rather difficult to get the exact order of deformation. 3 and 11 appeared to have the least viscosity, 2 and 10 were next. No. 13 was noted as having started. It proceeded no further and was probably due only to shrinkage.

In a general way this burn checks Burn No. 1.

Fourth Burn (Series II).—This burn included 2, 3, 10, 11, 4, 17, 18 and 24 which deformed in Burn No. 3. (Fig. 2-II.)

Started 10:00 A. M. Heated slowly. Put on full heat at 1:00 P. M.

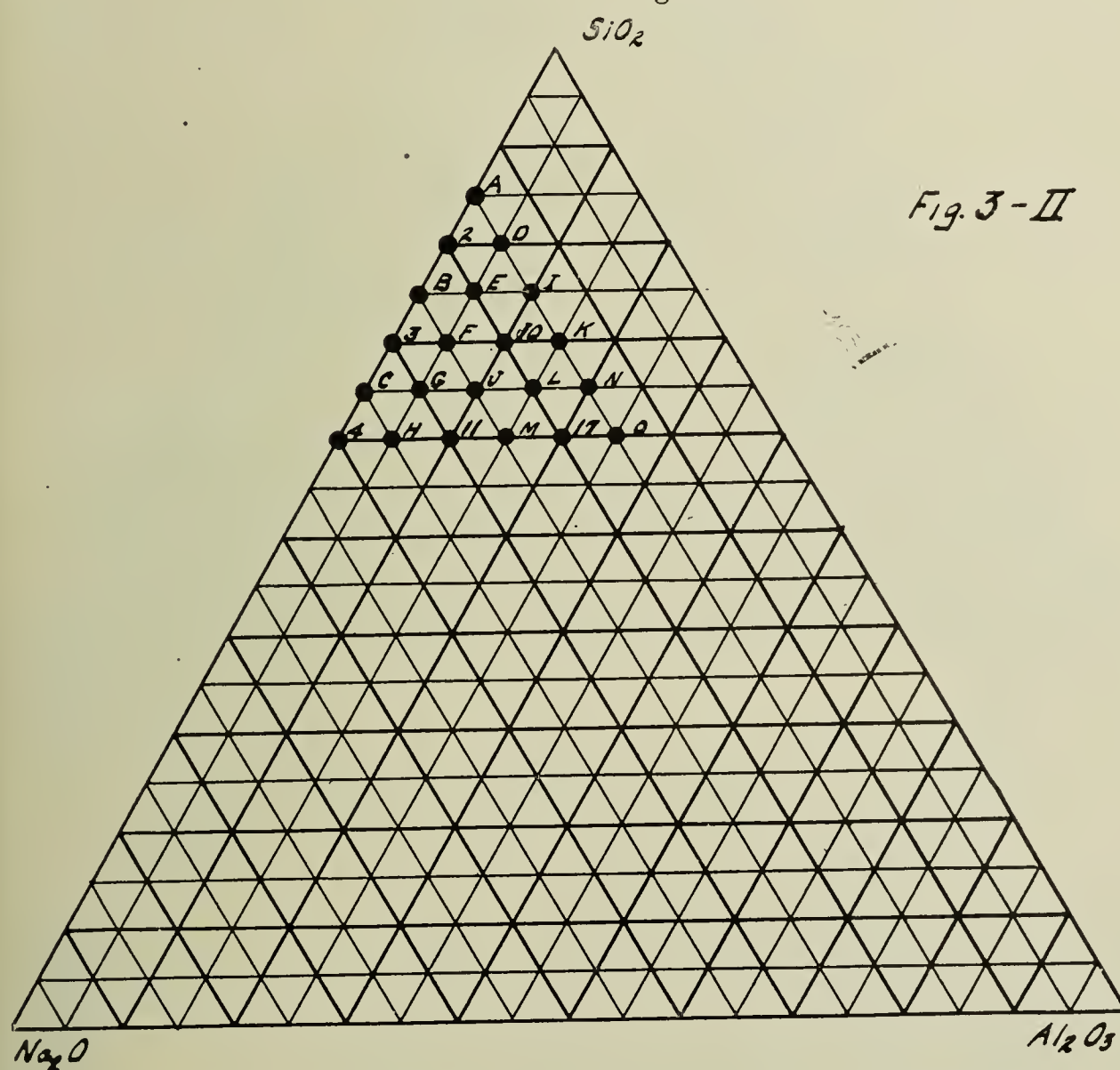
Time	M. V.	Temp. °C	Remarks
1:30	8.5	570	
1:55	10.2	705	
2:00	Power off.	Came on again at 2:30	
2:30	7.5	480	
2:40	8.8	590	
2:55	10.2	705	
3:02	10.8	760	10 started
3:05	11.0	770	2 started—17 started backwards
3:10	11.3	795	3 and 11 started
3:12	11.35	800	10 down—17 started forward
3:15	11.5	810	11 down just a trifle ahead of 2 and 3 4 started
3:19	11.75	835	17 down. 18 started
3:20	11.8	840	4 down
3:22	11.9	845	18 down
Started.....	10	2 2-11	17 4 18 24
Down.....	10	11 2	3 17 4 18

From the above data it will be seen that the positions of 10 and 11 are reversed in order. Again 3 and 11 appeared to have least viscosity when observed after removal from furnace. This burn, while not checking Burn No. 3 exactly, does emphasize the fact that the most fusible area

thin 10% limits lies within the triangle bounded by No. 4 and points out half way between 2 and 1, and 17 and 22. Burn No. 5 will be confined to these limits and 5% steps will be taken in place of 10%.

Fifth Burn (Series II).—This includes members of entire triaxial bounded by members A, 4 and O, (Fig. 3-II). 5% limits. Started 2 P. M.

Time	M. V.	Temp. °C	Remarks
2:00	2.0	...	
2:25	3.2	...	
3:10	8.7	570	
3:25	9.8	675	
3:40	10.9	765	
3:45	11.1	780	10, L, B, E probably started, hard to see
3:50	11.4	805	F started
3:52	12.0	855	F, E, 10 and B down in order. J, L, M, 2 and O had just started in order given

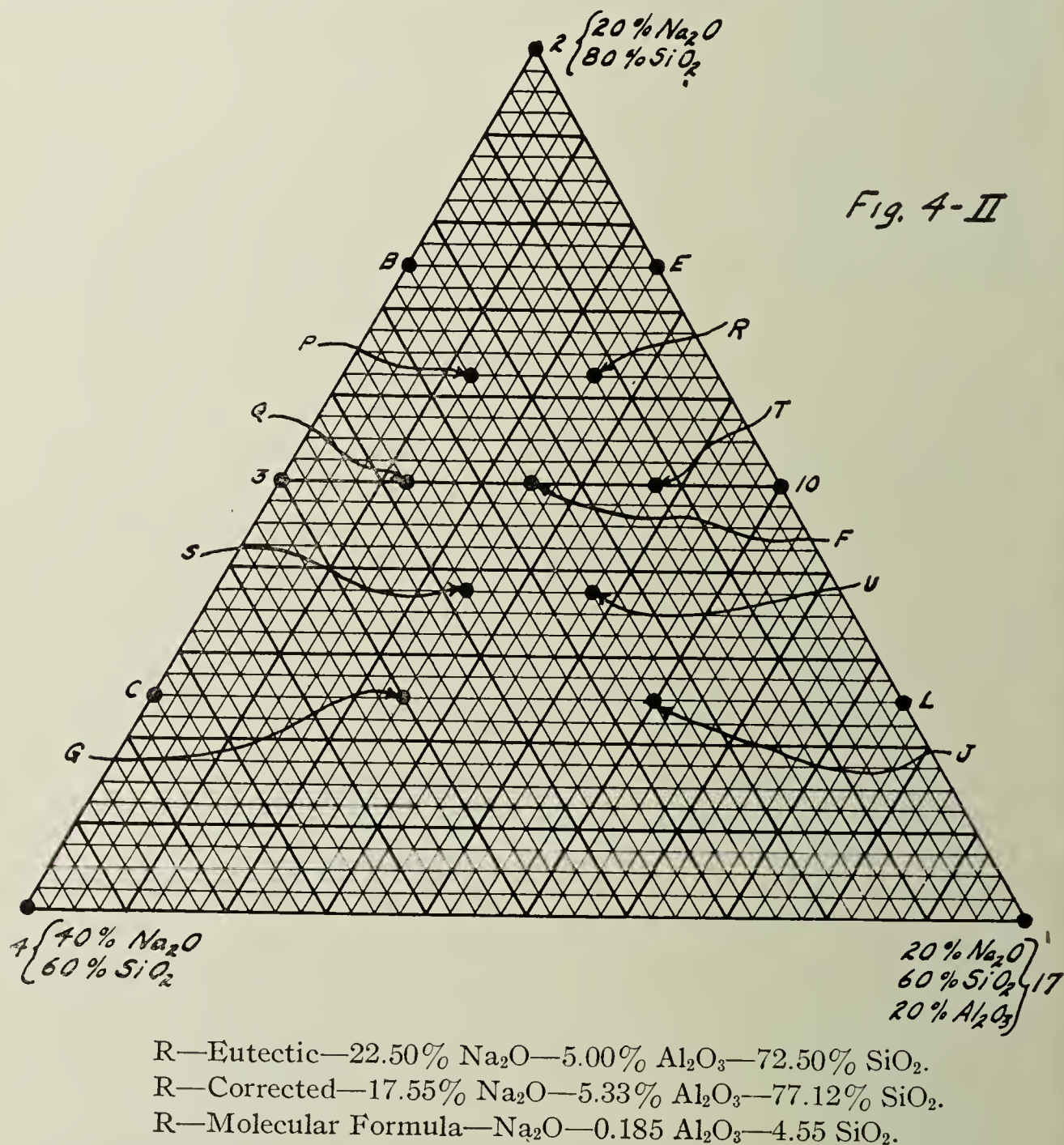


This burn nicely checks previous results. F was decidedly the most fusible, with E next followed by 10 and B which were practically together. With the exception of these four members none of the cones deformed to any great extent. This establishes the fusible area pretty closely. The next burn will be to establish the deformation eutectic as near as possible within $2\frac{1}{2}\%$ limits.

This burn gives B as a eutectic on the straight line $\text{Na}_2\text{O}-\text{SiO}_2$. In the first two burns of this series a eutectic was indicated at 51.5% Na_2O 48.5% SiO_2 . B has composition 18.4% Na_2O , 81.6% SiO_2 . So we have

1. 18.4% Na_2O -81.6% SiO_2 (Na_2O -4.579 SiO_2) 5% limits 860°C.
5. 51.5% Na_2O -48.5% SiO_2 (Na_2O -0.972 SiO_2) 10% limits 830°C.

The above figures are corrected according to analysis of Na_2CO_3 .



The only data published on $\text{Na}_2\text{O}-\text{SiO}_2$ which has come under the observation of the writer is by C. J. Peddle, "The Development of Various Types of Glass. Part I. The Interaction of Silica with the Oxides of Sodium and Potassium."¹ This work deals with solubilities and refractive indices of various compositions. However, the statements are made "Glasses of the type containing more than 75% SiO_2 require temperatures greater than 1300°C for their production." "Glasses containing less than 70% SiO_2 all melt down at temperatures below 900° (C)." He employed

¹ *Loc. cit.*

the following method of fusion: the crucible was heated to desired temperature and material introduced by three fillings at half hour intervals and the batch held at this temperature for $3\frac{1}{2}$ hours. He found that the potash glasses reacted at lower temperatures than the soda glasses.

Sixth Burn (Series II).—This brings the limits to $2\frac{1}{2}\%$ and includes members F, R, Q, P, U, T, S. (Fig. 4-II.)

Cones were placed in furnace with thermocouple registering 5.5 m. v. at 2:15.

Time	M. V.	Temp. °C	Remarks
12:30	8.8	595	
12:50	10.6	740	
12:53	10.8	760	U started
12:55	11.1	780	R started—P and Q have tilted backwards slightly
12:57	11.2	790	F started
1:00	11.4	805	R down—T started
1:02	11.5	810	Q, S, P started
1:03	11.6	820	U, T, S and F down. Cones removed from furnace

At this point R seems to be the softest with T and U next in order. The cones were placed back in the furnace at red heat (8.6 M. V.) and temperature brought up to deformation point again and held to see if any idea of viscosity could be obtained.

Time	M. V.	Temp. °C	Remarks
2:00	8.6	580	
2:20	10.6	740	
2:25	11.3	800	P down
2:30	11.6	840	Cones removed from furnace

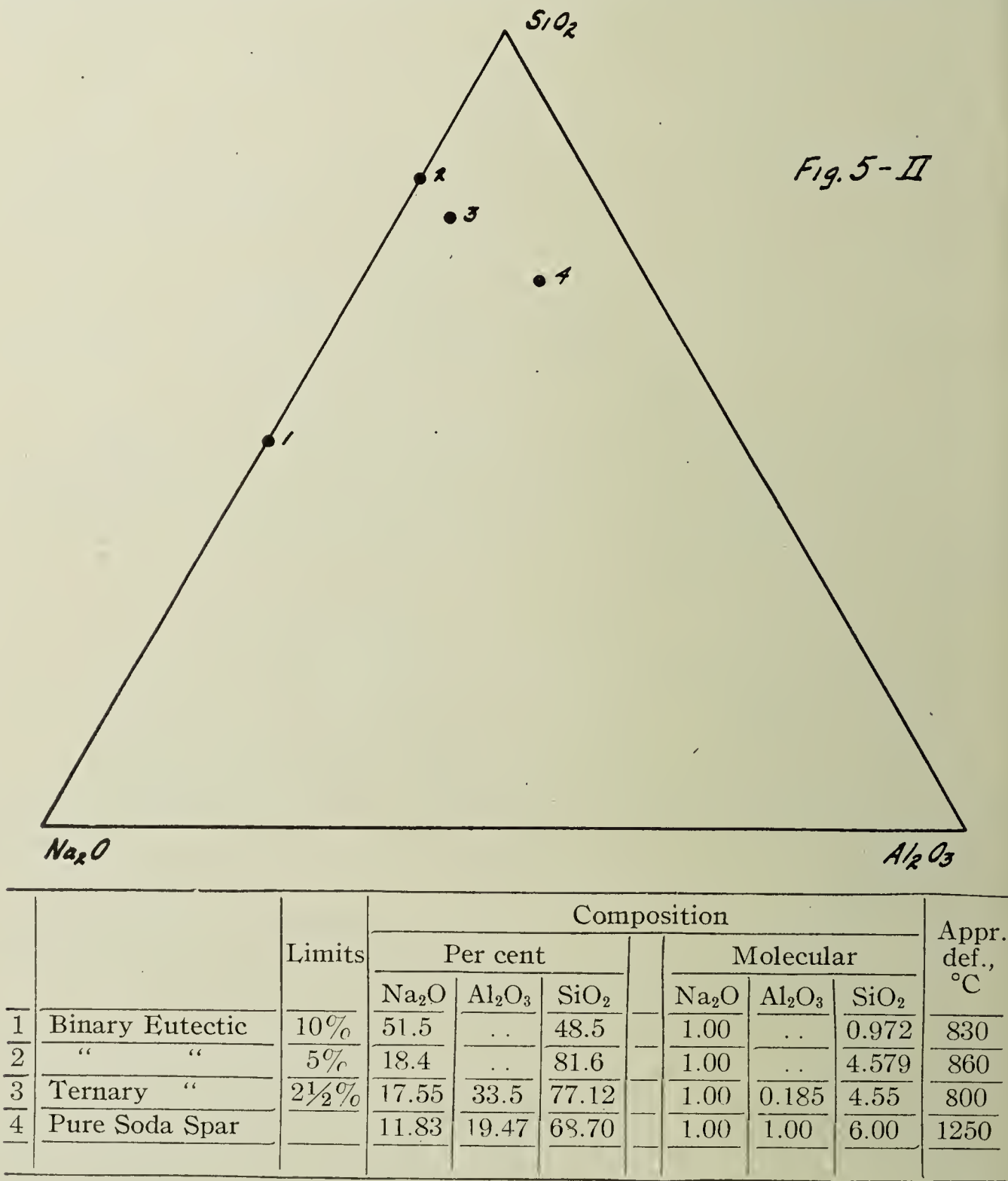
From observation of degree of deformation after the second heating R, F and S appear distinctly softer than the others. Of these three, R seems the softest, followed by F and S in order.

It will be noted that the three softest members lie along a common Al_2O_3 line. This would seem to indicate that Al_2O_3 is the constituent most active in regulating the deformation point.

R is decided upon as the deformation eutectic of the system; $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$, within $2\frac{1}{2}\%$ limits. It must be made plain though that the difference in deformation temperature of three members is small, only a few degrees. Relative deformation was the object in view and exact temperature measurements were not attempted as it would require a high degree of accuracy to ascertain these when the variation in composition is as low as 2.5%.

From the triaxial R has a composition 22.5% Na_2O , 5% Al_2O_3 , 72.5% SiO_2 which, when corrected according to analysis, gives 17.55% Na_2O , 5.33% Al_2O_3 , 77.12% SiO_2 .

One is immediately struck with the fact that the percentage composition is nearly identical with that of the $K_2O-Al_2O_3-SiO_2$ deformation eutectic and, when methods and raw materials are considered, may be considered the same. The temperatures at which deformation took place are not widely different, $800^{\circ}C$ for the soda eutectic and $870^{\circ}C$ for the potash. From this it may be said that K_2O and Na_2O have the same fluxing value *pound for pound* when introduced in the form of carbonates. This



is in accord with the statement made by Homer F. Staley,¹ "When introduced from corresponding soluble salts, Na_2O and K_2O , are equivalent, pound for pound."

In working out the $CaO-Al_2O_3-SiO_2$ and $MgO-Al_2O_3-SiO_2$ eutectics

¹ *Trans. Amer. Ceram. Soc.*, **13**, 504 (1911).

The Geophysical Laboratories found two areas of low fusibility towards the SiO_2 end of each triaxial. In the case of the former there was one near the $\text{Na}_2\text{O}-\text{SiO}_2$ line and in the case of the latter, near the $\text{MgO}-\text{SiO}_2$ line, these points corresponding somewhat to those found in the $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ and $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ triaxials. They also found points approaching the $\text{Al}_2\text{O}_3-\text{SiO}_2$ line in both cases which leads one to believe there might be similar points in the $\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ and $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ triaxials. The field was not carefully studied to see if such exist because the temperatures were much higher and the low temperature points established were the ones desired.

Conclusions

1. The members toward the high Na_2O corner with an Na_2O content above that of member No. 5 have a stony or slag-like appearance and are not glossy like those toward the high SiO_2 end.

2. Two deformation eutectics are found on the straight line $\text{Na}_2\text{O}-\text{SiO}_2$

(a) 51.5% Na_2O
48.5 SiO_2
(830°C)

(b) 18.4% Na_2O
81.6 SiO_2
(860°C)

3. A ternary deformation eutectic was found of the composition:

17.55 Na_2O
5.33 Al_2O_3
77.12 SiO_2

4. The deformation temperature of this eutectic is 800°C and approaches that of a glass or enamel. It is close to that of $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ eutectic which was 870°C.

5. This eutectic has a lower alumina content than any natural sodium-aluminum-silicate mineral known.

6. The composition of the ternary eutectic is practically the same in percentage composition by weight as that of the $\text{K}_2\text{O}-\text{Al}_2\text{O}_3-\text{SiO}_2$ system. Consequently it may be said that Na_2O and K_2O have the same fluxing value pound for pound when introduced in the form of carbonates.

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ELYRIA, OHIO

THE CONTINUOUS SYSTEM OF GRINDING CERAMIC MATERIALS¹

BY HARLOWE HARDINGE

Introduction

It is well to point out at the outset that we make no claim of being ceramic engineers with a knowledge of the industry as a whole. We have been called specialists, and perhaps that is the best term to use in this instance, as we specialize in one branch only of this most important industry. I mention this point now in an endeavor to make it clear that what we have done in the matter of grinding various materials required in the ceramic industry, has been accomplished through our knowledge of grinding and what can be done under given conditions. We are not trying to alter the conditions as they exist, but simply point out a method whereby the information we have obtained from many years' experience in other fields may be used to advantage in the ceramic industry.

The methods which I am about to describe are not experiments, unless one might consider every installation an experiment due to the conditions surrounding each as being different from its neighbor. Our work has been directed to both the wet grinding and dry grinding of the many materials. This discussion, however, will deal mainly with feldspar, silica, grog, and enamel frit, as these are typical materials illustrating the new methods which are now being applied with considerable success.

Feldspar and Silica

Taking up first the most important of these fields, that is, the grinding of feldspar, what I am endeavoring to show is a method known in a general way by many, but fully comprehended by comparatively few, as it has only recently been introduced into the ceramic industry. This is the "continuous" system of grinding. There are a number of methods which have been used in the past which might be considered as semi-continuous but to my knowledge none have been entirely continuous, especially when fine grinding is required.

The application of the continuous system for grinding silica is similar to that of feldspar, hence the systems herein described for the grinding of feldspar will apply to the grinding of silica whether wet or dry, and in fact, are being used today under almost parallel conditions.

Rather than take a hypothetical case, I have obtained permission to use as an illustration an actual installation now in successful operation. I will give the facts as they are today. The installation which I will describe

¹ Paper presented before the AMERICAN CERAMIC SOCIETY at the Exposition of Chemical Industries, New York City, September 15, 1922.

s that of the Golding-Keene Company, Keene, N. H., which is grinding feldspar dry.

Mine

The Keene Mica Products Company is operating a feldspar property located about 11 miles from Keene, N. H., and is selling their product to the Golding-Keene Company at Keene, N. H. The former company has been operating the property for a number of years for the mica which occurs along the walls of a feldspar dike. This feldspar dike is about 50 to 100 feet wide and has been traced over an entire hillside.

The property was developed by opening up a large pit on the feldspar dike and later drifting in along the dike. The bench system of mining similar to that employed in limestone mining, is used. The pit is about 100 feet across and about 75 feet deep. Another pit similar to the first one is being opened about 300 feet away and directly on the dike. Drifting will be done on this opening to meet the tunnel from Pit No. 1. The deposit has been thoroughly prospected and the estimate that 500,000 tons of feldspar are in sight is conservative.

Being at rather a high altitude for this section of the country, very little water is encountered, therefore no pumping is necessary. The feldspar is shot down from the benches with dynamite, the holes for which are drilled with air drills.

The feldspar is then sorted into two grades according to silica and mica content, No. 1 being the purer grade. This sorting is accomplished at the mine by hand cobbing. At present, the feldspar is hoisted by means of a bucket and steam hoisting derrick and deposited in bins alongside the roadway. The drifts are not advanced far enough to necessitate hauling the feldspar to the pit opening, but as soon as these have advanced to where they will not permit of loading directly into the buckets, the feldspar will be loaded into mine cars and trammed to the opening.

Milling Plant

The milling machinery is installed in one of the brick buildings of the Keene Mica Products Company, at Keene, N. H. The feldspar is hauled from the mine 11 miles away by motor trucks.

The mill building contains the crude storage or crushing room and the grinding room. The feldspar is stored on the floor of the storage room into separate piles of No. 1 and No. 2 feldspar. The following are analyses of their two grades of feldspar:

		Analysis of No. 1 feldspar, "Puritan"	Analysis of No. 2 feldspar, "Keene"
Silica	SiO ₂	66.45%	69.59%
Alumina	Al ₂ O ₃	19.45	16.99
Lime	CaO	.00	.65

Iron oxide	Fe ₂ O ₃	0.07	0.09
Magnesia	MgO	.11	.27
Potash	K ₂ O	11.04	10.20
Soda	Na ₂ O	2.75	1.68
Loss in ignition		.15	0.70
		<hr/>	<hr/>
		100.02	100.17

From the storage piles, the feldspar is fed into a 9" x 16" Reliance jaw crusher, equipped with flat manganese steel jaw plates, designed for fine crushing and set to deliver 1/2-in. product. This crusher is driven from a 20-horse power motor and discharges its product into an elevator equipped with manganese steel buckets to eliminate any chance for iron contamination. The elevator lifts the crushed feldspar to a 20-ton storage bin.

The crushed material is fed by means of a regulating disc and manganese steel chute feeder into an 8-ft. diameter by 36-in. cylinder Conical Pebble Mill. The top of the disc measuring feeder is covered with hard wood to eliminate the introduction of any metallic substances, and the feeder table itself is driven by chain drive from the mill countershaft. The mill is especially designed for dry grinding, having 23-in. diameter main bearings which are water-jacketed for water-cooling. The mill countershaft is driven from a 60-horse power slip ring, 685 r. p. m. full load speed General Electric motor through a Link-Belt silent chain drive. The mill itself is equipped with a 136-tooth, 9-ft. diameter by 8-in. face gear and this gear is driven from a 17-tooth pinion on the countershaft. The discharge end of the mill is equipped with a circular wire screen about 10 inches long and 24 inches in diameter with about 1/4-in. square opening. The purpose of this screen is to catch broken pebbles or coarse lumps and keep them from going into the circuit. It also serves to act as an indicator as to whether or not the mill is being overfed. Presence of a great many coarse lumps in this trommel is an indication of overfeeding.

The mill is operated at a speed of 27 r. p. m. and carries a pebble charge of

	5,000 pounds	5 inches
	3,000 pounds	4 inches
	3,000 pounds	3 inches
	1,800 pounds	2 inches
		<hr/>
Total	12,800	

The feed to the mill runs about as follows:

Through 1-in. ring	100%
Through 2-mesh	89.9%
Through 4-mesh	61.8%
Through 12-mesh	43.8%

The moisture in the feed averages about 2% by weight.

The product discharged from the mill is elevated to a 14-ft., Moore

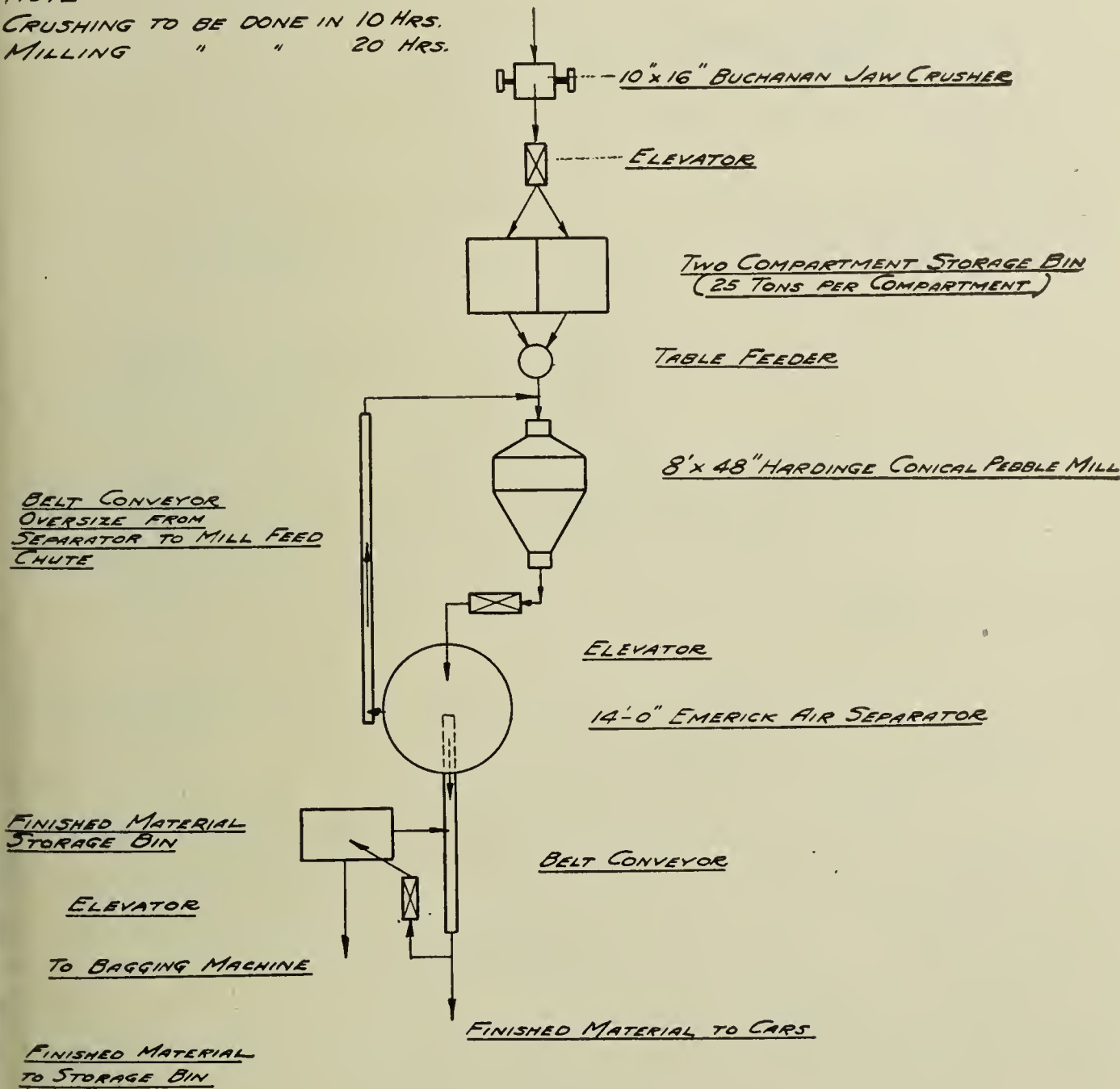
21, Gayco Emerick air separator by means of a belt and bucket elevator equipped with manganese steel buckets. This elevator feeds a short belt conveyor feeding the air separator. The feed to the air separator runs as follows:

Through 140-mesh	70 to 80%
Through 200-mesh	55 to 60%
Through 300-mesh	40 to 50%

The product coming from the separator runs as follows:

Through 140-mesh	99.8%
Through 200-mesh	96 to 98½%
Through 300-mesh	91 to 92%

NOTE
CRUSHING TO BE DONE IN 10 HRS.
MILLING " " 20 HRS.



NOTE
IF MOISTURE IS OVER 2% INSTALL
DRYER BETWEEN STORAGE BIN AND
HARDINGE MILL

FIG. 1.—Arrangement of a feldspar or silica grinding plant having a capacity of 1½ to 2 tons per hour.

The capacity of the mill and separator delivering this product is 2,600 pounds per hour, although at times it is possible to go up to 2 tons per hour. The coarse tailings from the separator are discharged on to a belt conveyor which returns them to the feed table ahead of them all. Tests show that the air separator takes 85% to 90% of the 140-mesh and finer material out of the mill discharge. No matter what the condition of the feed to the air separator is in, the separator continues to deliver a uniform product having the same fineness.

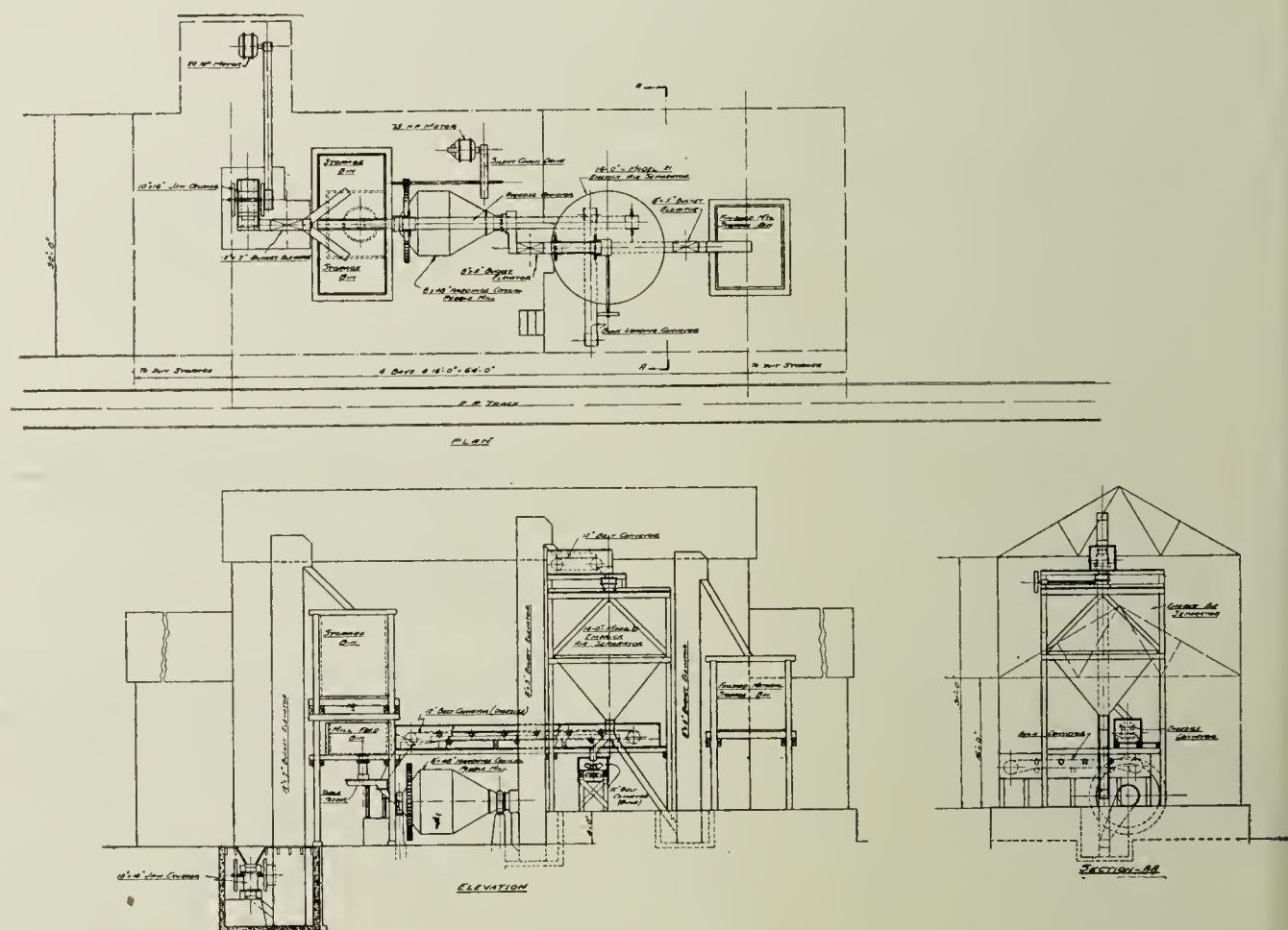


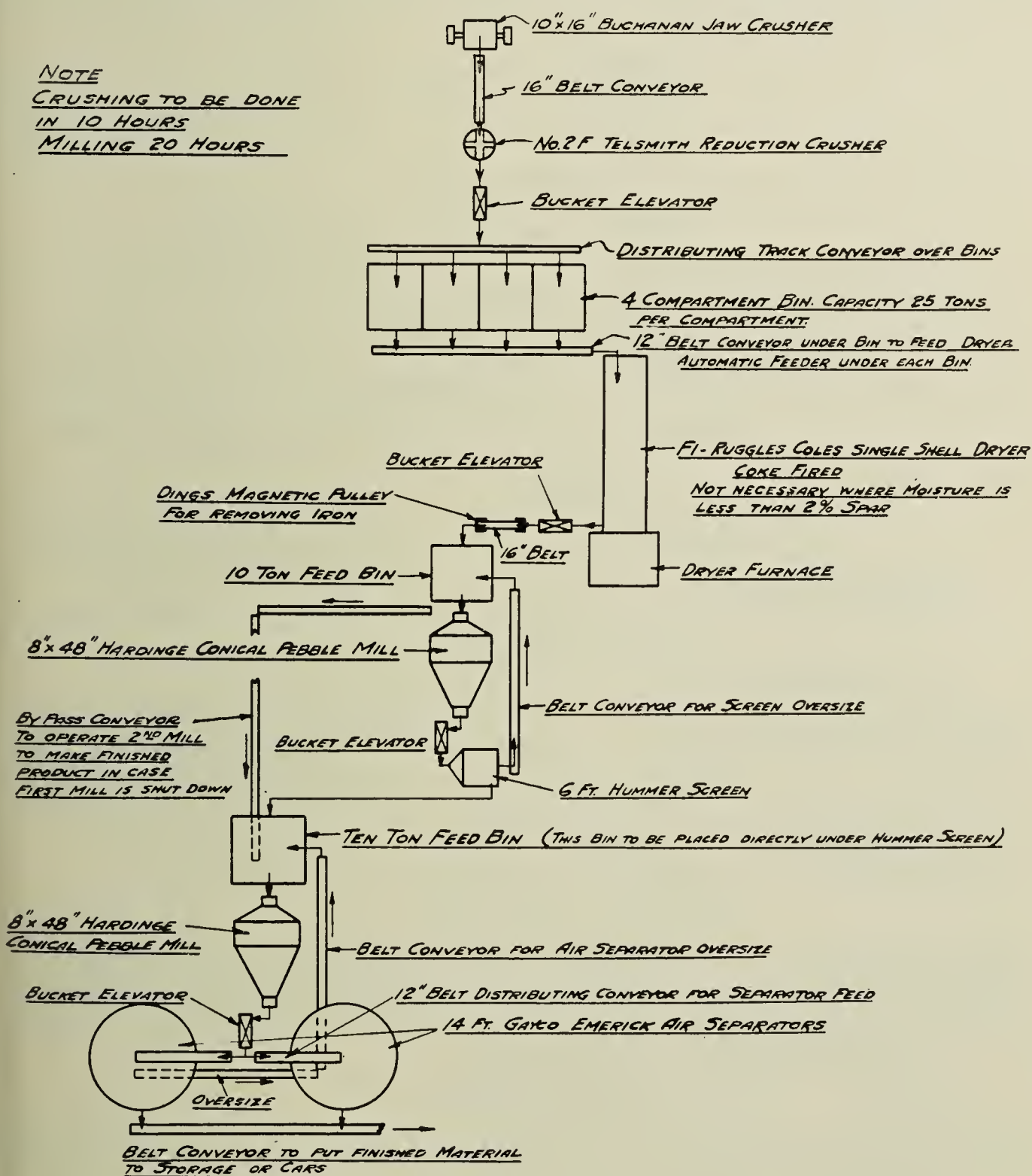
FIG. 2.—General arrangement of a simple feldspar or silica grinding plant having a capacity of $1\frac{1}{2}$ to 2 tons per hour.

The Gayco Emerick air separator consists briefly of an outer shell with separating chamber, tailings cone, baffle plates, feed pipe on which are attached the fans, driving mechanism and distributing plate. The main fan causes a lifting action while the small fan in the separating chamber causes a centrifugal separation. By various adjustments on the centrifugal fans, the resultant of the two forces, lifting and centrifugal, can be varied to obtain almost any fineness of product desired which is little affected by atmospheric changes or variations in feed.

The finished material is discharged on to a belt conveyor which feeds directly into the box cars or into an elevator which in turn lifts the material to a storage room.

The Gayco Emerick air separator takes about 10 h. p. and operates

a countershaft speed of 250 r. p. m. which causes a fan speed of 160 r. p. m. The elevators and belt conveyors take about 10 h. p. more, and actual readings on the Hardinge mill motor showed that this mill is taking 55 h. p. The entire installation is consuming about 90 h. p., but the jaw crusher crushes enough on a 12-hour shift to keep the mill running 24 hours.



IG. 3.—4-ton per hour dry grinding plant for feldspar or silica using Hardinge Mills and Emerick air separators.

Aside from a few minor troubles with auxiliary machinery, this plant has operated steadily since its start about three months ago.

They recently decided to increase the capacity by installing an 8-ft. diameter by 48-in. cylinder Hardinge Conical Pebble Mill and another 4-ft. Gayco Emerick air separator. The new unit is calculated to give

them 2 tons per hour and will be installed beside the existing grinding unit.

Fig. 1 shows the arrangement of a typical unit which is very similar to that described above. Fig. 2 is a drawing of the plan and elevation of such a unit.

I feel greatly indebted to the management of the Golding-Keene Company and am very glad to express my appreciation for their allowing me to

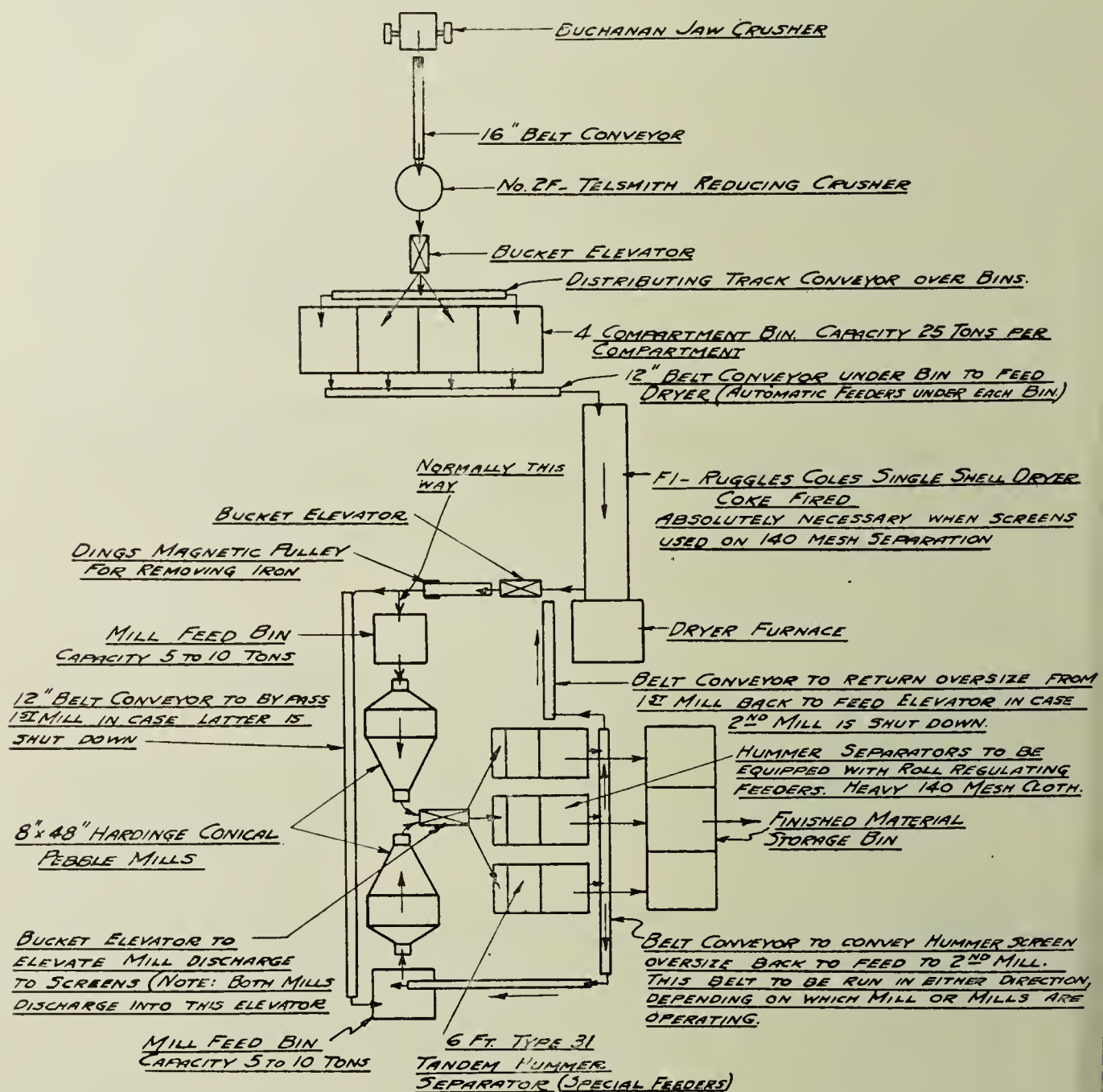


FIG. 4.—3- to 4-ton per hour plant for grinding feldspar and silica by the dry process using Hardinge Mills with electric screens.

opportunity of describing to the members of the AMERICAN CERAMIC SOCIETY the operation of their plant.

General

It might be well to consider in passing that all conditions are by no means the same but the layouts of typical plants as here illustrated should insure a satisfactory product under all conditions and in all climates.

The layout shown in Fig. 3 is that of a complete plant grinding feldspar at the rate of 4 tons per hour. A drier is included in order to insure a dry feed under all climatic conditions. It should be noted that during normal operation the first mill is operated in closed circuit with a vibrating screen of relatively coarse mesh, the oversize of this screen going back to the preliminary mill for regrinding and the fine material going to the re-

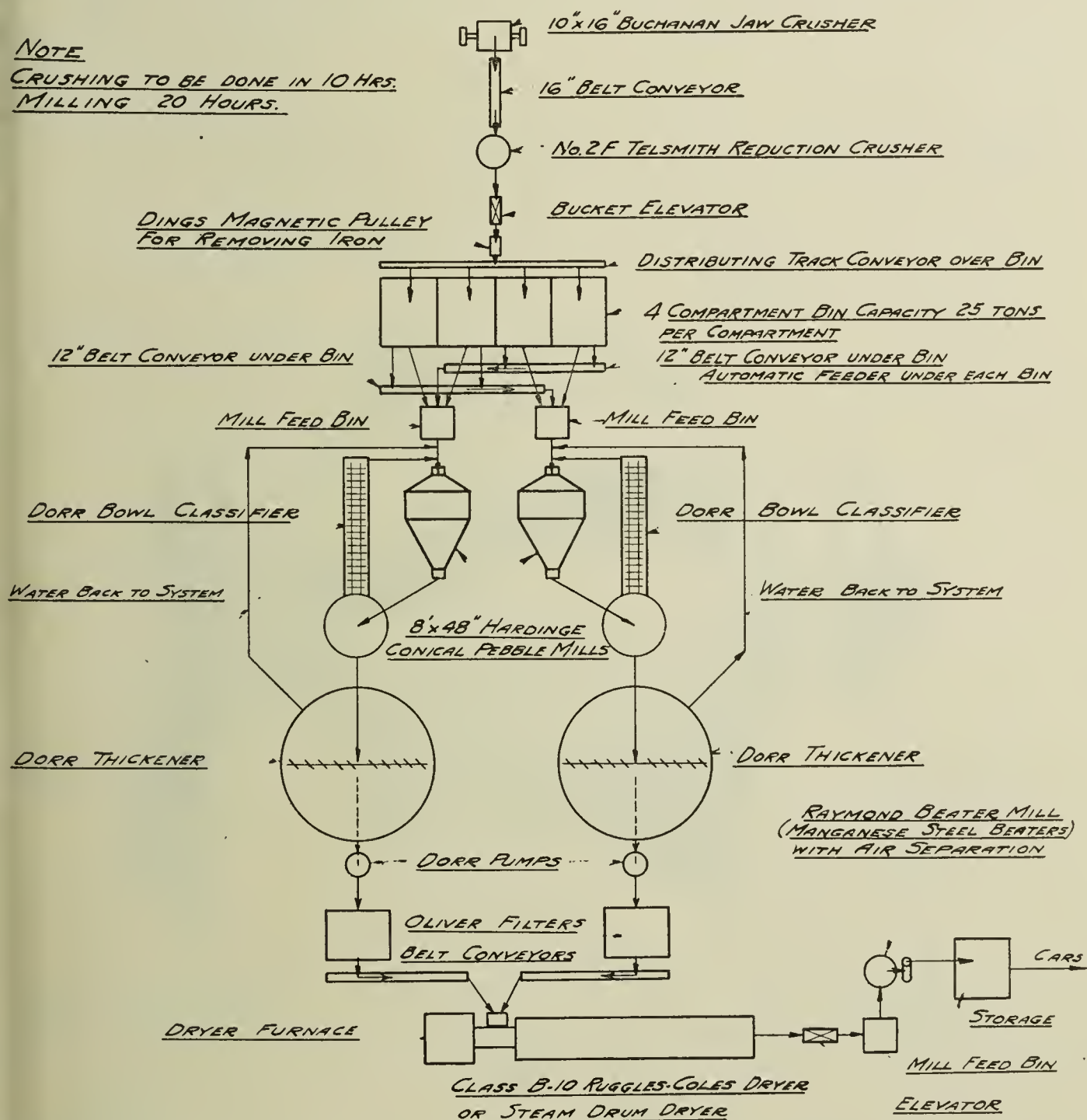


FIG. 5.—Typical layout of a wet grinding feldspar or silica plant having a capacity of 4 tons per hour.

grinding mill which is in turn in closed circuit with air separators. This layout has many advantages in that the drier not only insures a satisfactory feed to the mills in all kinds of weather but also increases the capacity of the grinding units. Note that in this instance, 8-ft. diameter by 48-in. cylinder pebble mills are used instead of an 8-ft. diameter by 36-in. cylinder mill as described in the plant of the Golding-Keene Company.

Fig. 4 illustrates another arrangement of a plant having the same capacity as the previous one, namely 4 tons per hour, but instead of using air separators, vibrating screens are employed. Here the arrangement of the milling unit is somewhat different. You will note that both mills may take the initial feed and discharge their product to screens, or in other words, each mill may take half the capacity of the plant, or the entire product may be sent to the first mill, then its product passed over the screens, the oversize going to the second mill whose product also goes over the first screens.

Fig. 5 illustrates a method of grinding feldspar by the wet process. This is a very good method, is economical to operate, and clean, but re

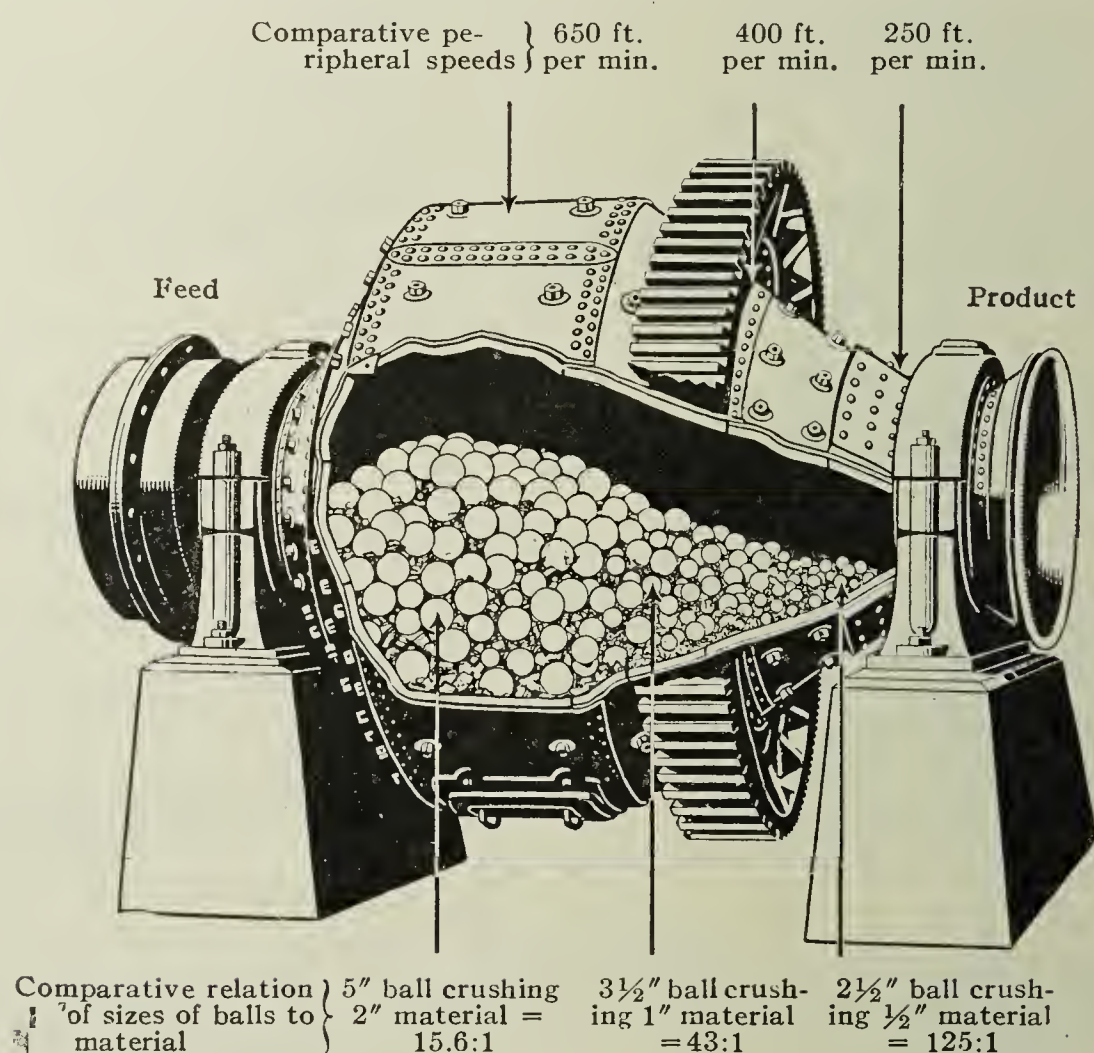


FIG. 6.—Illustration of the classification of balls and material within the Conical Mill.

quires a larger initial investment. Here driers must be used, for the finished product as it comes from the filters contains too much moisture while in the dry process, driers are not absolutely essential to successful operation especially when the moisture content of the feldspar going to the crusher is approximately 2%.

Grinding of Grog

The grinding of grog as recently developed is a far cry from that of feldspar but here again modifications of the method of treatment effect marked

economies where the grinding must be 10-mesh or finer. By using the Conical Ball Mill operated in conjunction with a revolving screen on the end of the mill or an outside vibrating screen, especially where products finer than 10-mesh are desired, the operation becomes simple and dustless. There is no denying that dry pans used for the grinding of grog to a product up to 6- or 8-mesh are more efficient than anything ever attempted, but

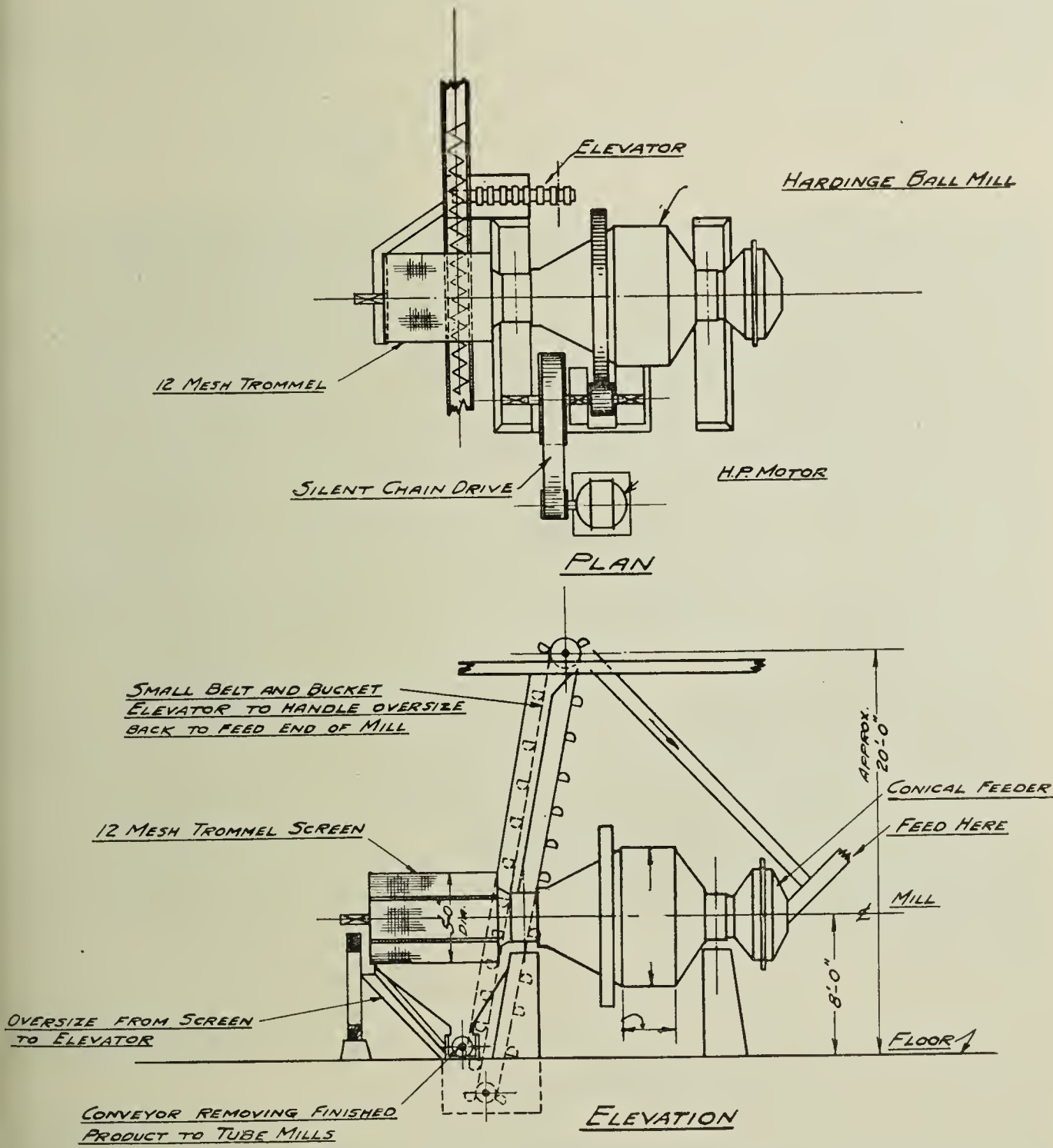


FIG. 7.—General arrangement of a Hardinge Ball Mill using heavy steel balls for grinding grog or Hardinge Pebble Mill using flint or porcelain pebbles for grinding enamel frit.

when it comes to grinding finer than 10-mesh, the whole aspect changes and it is just here where your attention is called to the application of the Conical Mill for accomplishing this work.

The Conical Mill in this case is usually supplied with steel balls and metal lining. Some of the balls used weigh as much as 20 pounds each. Before

we take up the results, it is well to consider how the mill operates so as to insure a product of the right characteristics and fineness. Usually it is desirable to have this product as uniform as possible and containing particles having sharp corners.

Owing to the action which occurs in the Conical Mill by virtue of the segregating effect which occurs in the cone, it will be found that as soon as the material has been ground, it travels very rapidly towards the discharge cone as it is unimpeded in its travel. This avoids overgrinding

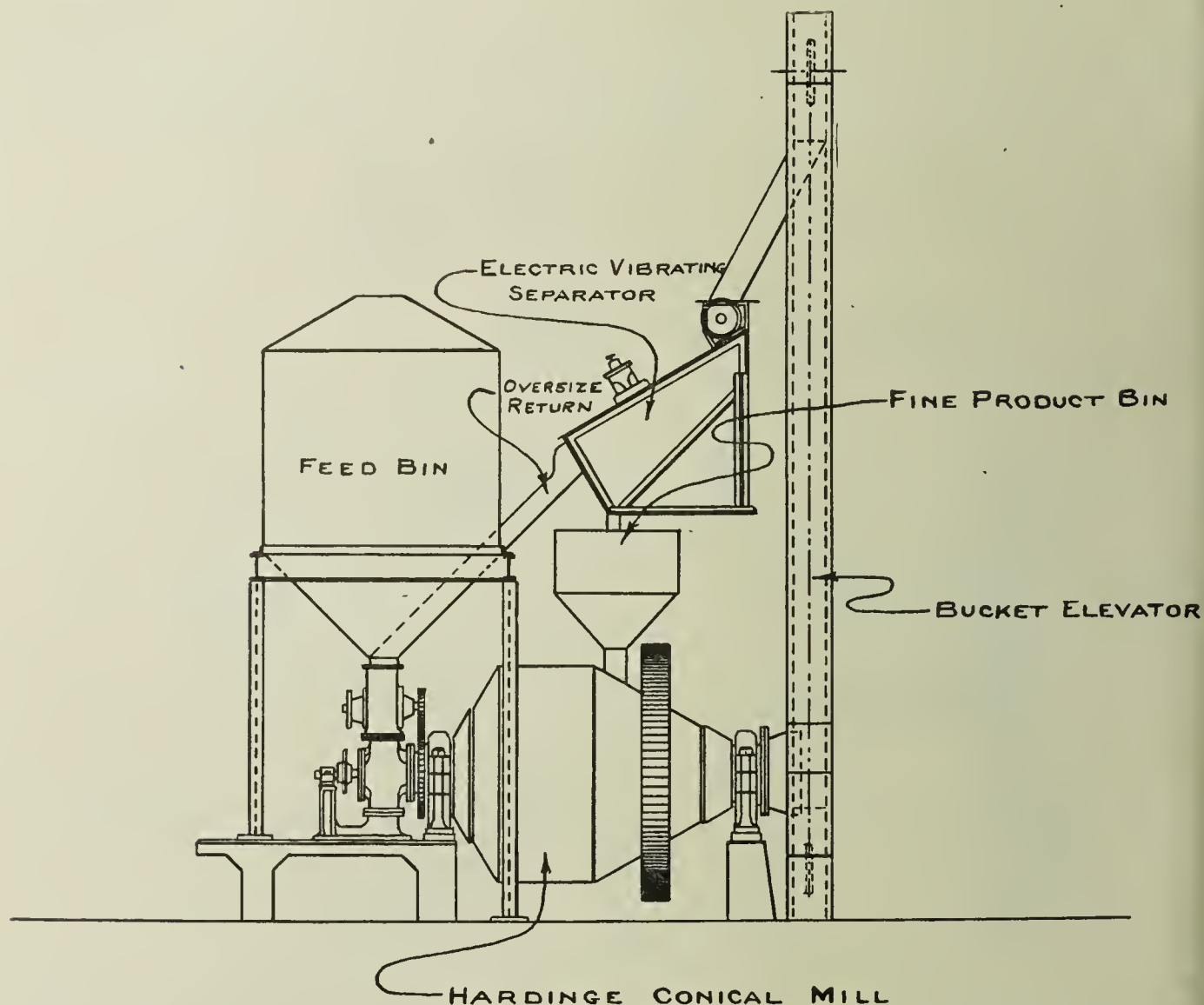


FIG. 8.—Typical arrangement of a unit consisting of a Hardinge Mill and electric screen for the grinding of enamel frit.

and it is for just this reason that the proper product is obtained at a high capacity compared with the power expended. (See Fig. 6.) The material discharged from the mill contains a far greater quantity of finished material than is the case with the ordinary dry pan. This reduces the load on the screens and consequently reduces screening and elevator troubles. The mill being entirely enclosed is dustless in operation, and since the grinding media are balls crushing against the heavy metal lining, the wear is very slight; in fact, in one case I have in mind where harder material than ordinary grog is being ground to the same specifications, a mill has been

operating for five years and the maintenance charges have been so small that, except for ball wear which amounts to $\frac{1}{10}$ lb. per ton, or about six tenths of a cent per ton, they cannot be estimated.

As an illustration of what this mill will do, a 5-ft. Conical Ball Mill taking a feed of 2 inches consisting of broken fire brick, pots, etc., will ordinarily have a capacity of about 3 tons per hour delivering a product all through 30-mesh and requiring about 35 h. p., the mill of course operating in conjunction with a screen, the oversize being returned for regrinding. Where a coarser product is desired, the capacity is considerably increased as might be expected. Fig. 7 illustrates a typical layout.

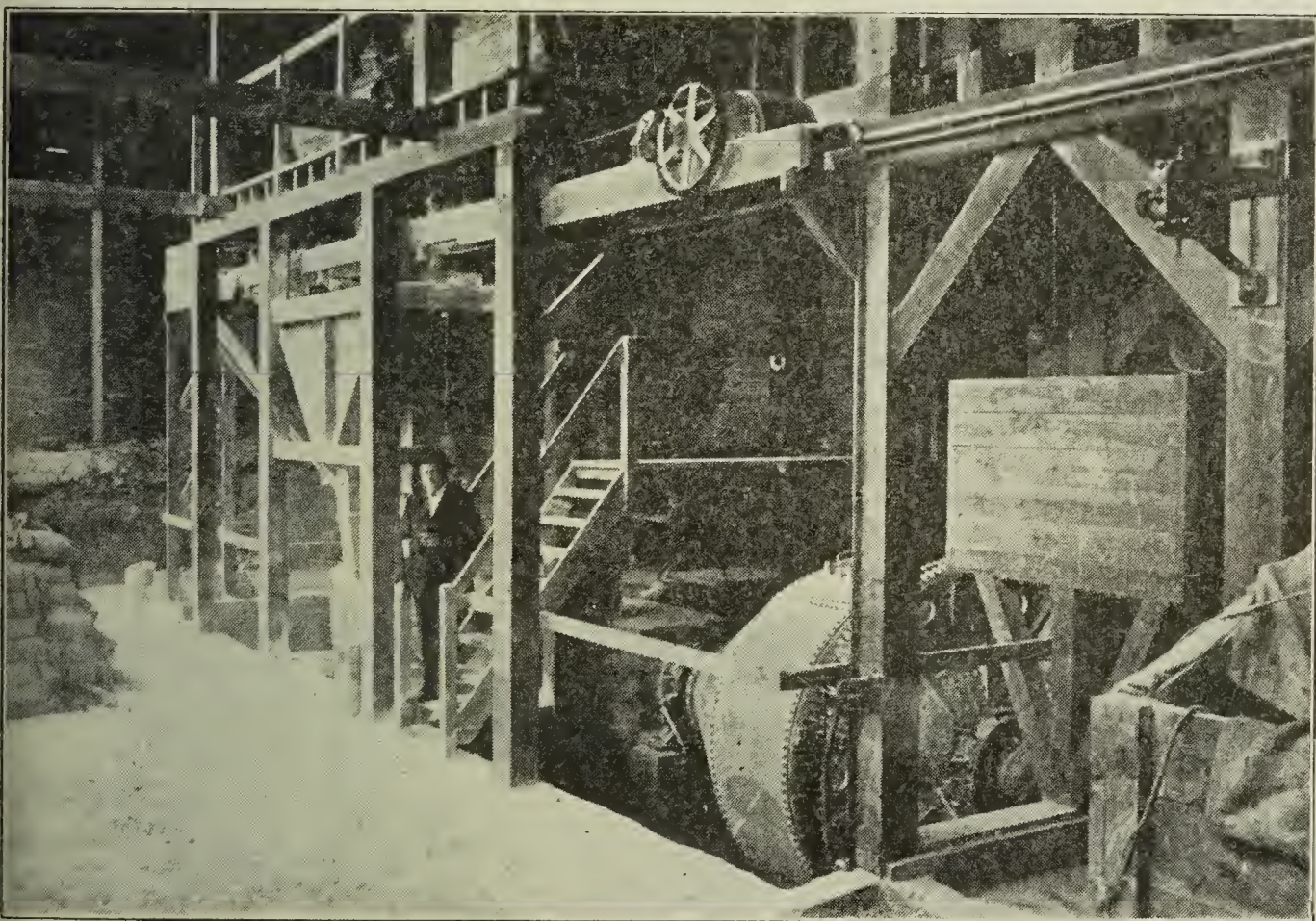


Fig. 9.—General view of the mill operated by the Cleveland Feldspar and Products Co.

Grinding Enamel Frit

The Conical Mills for grinding enamel frit, unlike those for grinding other materials, are usually lined with porcelain or silica to prevent any possible contamination, the grinding media being flint or porcelain pebbles. Instead of employing the ordinary batch system, that is, loading the mill through a manhole, then closing up and running for a number of hours, usually dumping the mill and shoveling into a screen, the operation consists simply of dumping in a quantity of the frit at the feed hopper of the mill, the feed then automatically entering the mill and after being ground passes out of the discharge at a continuous rate. It is usually found best

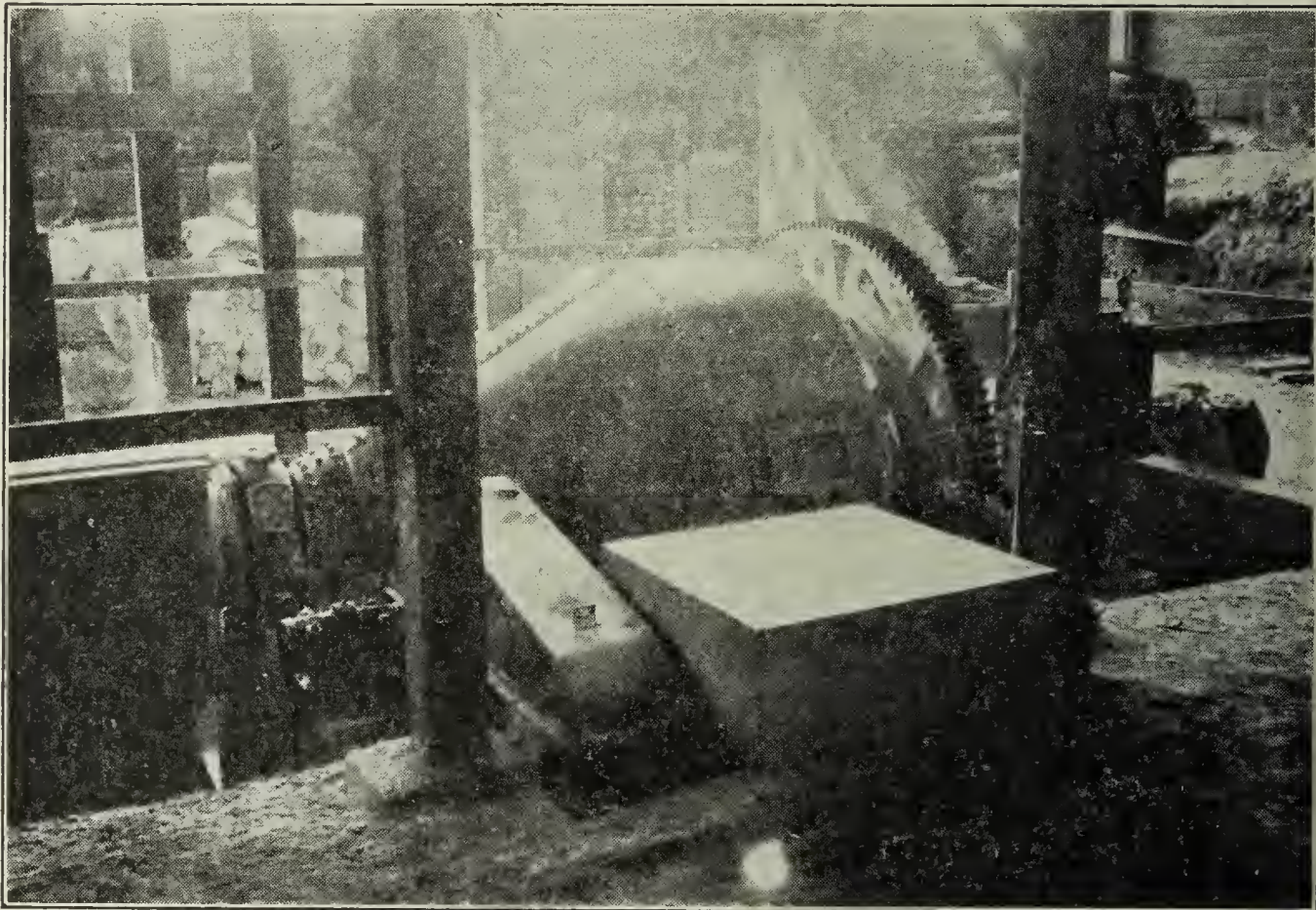


Fig. 10.—Pebble Mill operated by motor with chain drive, a very satisfactory method.

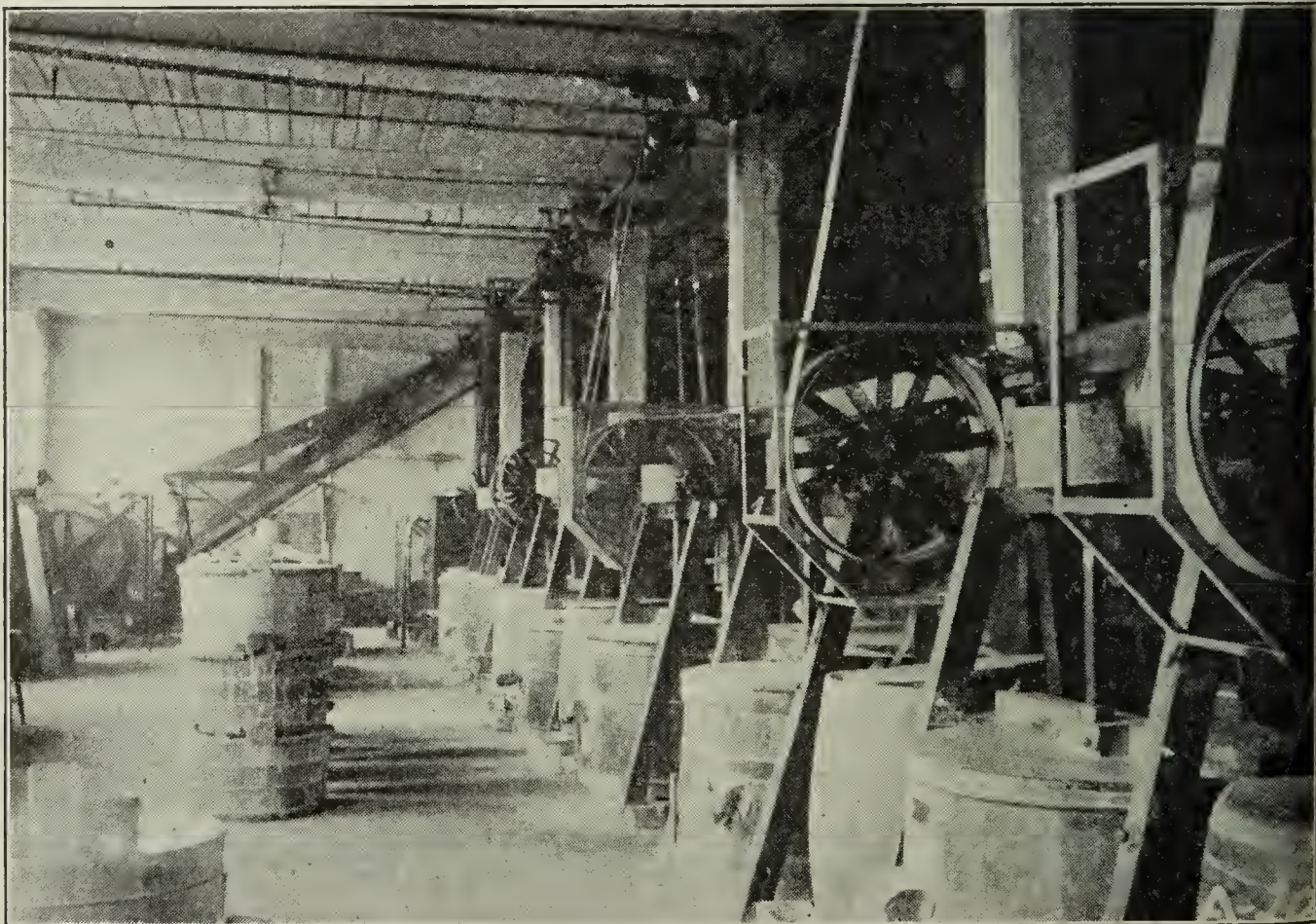


Fig. 11.—Old grinding tubes replaced by the Conical Mill and bowl classifier.

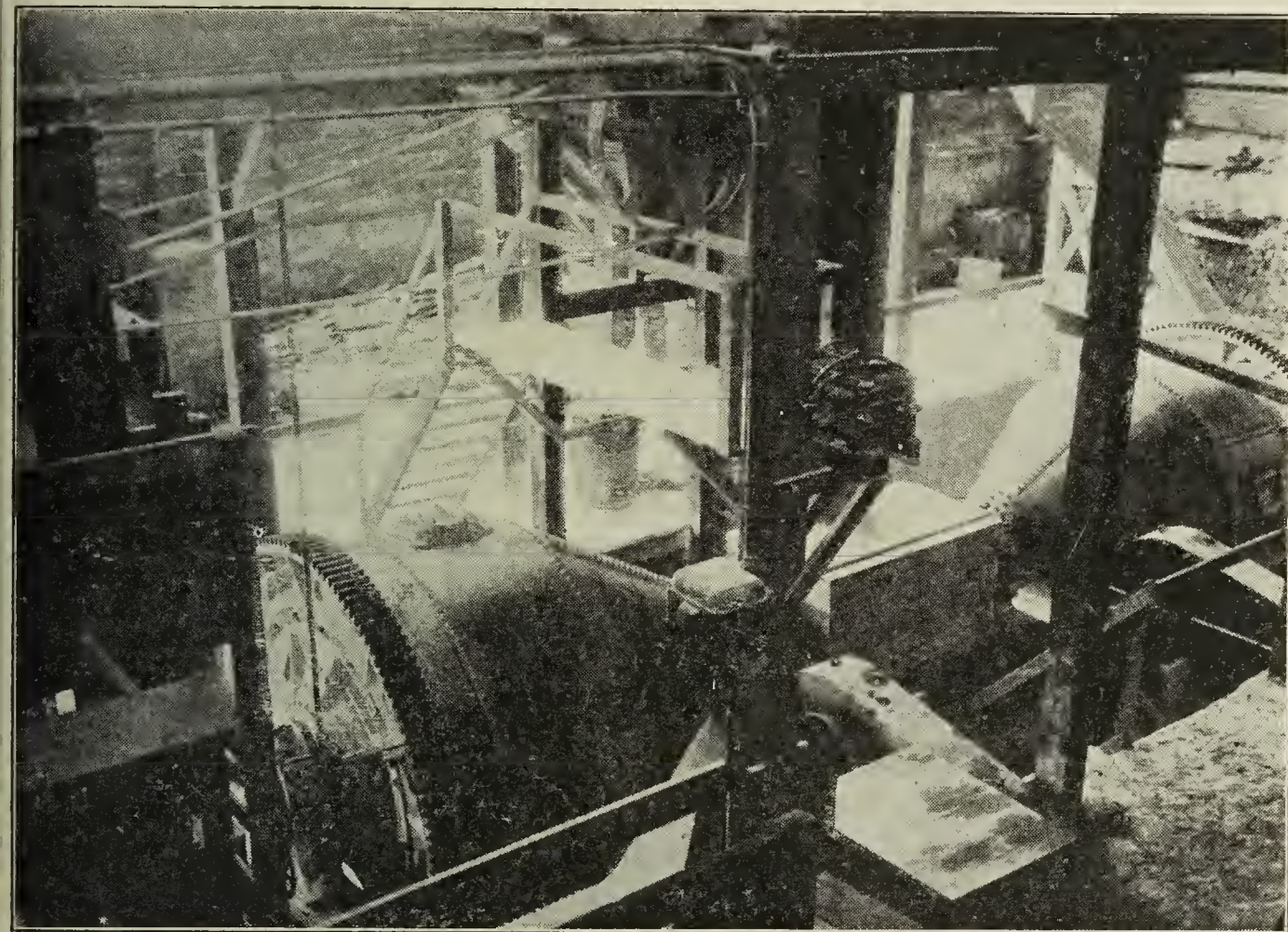


Fig. 12.—Arrangement of Conical Mills in a plant grinding feldspar dry.

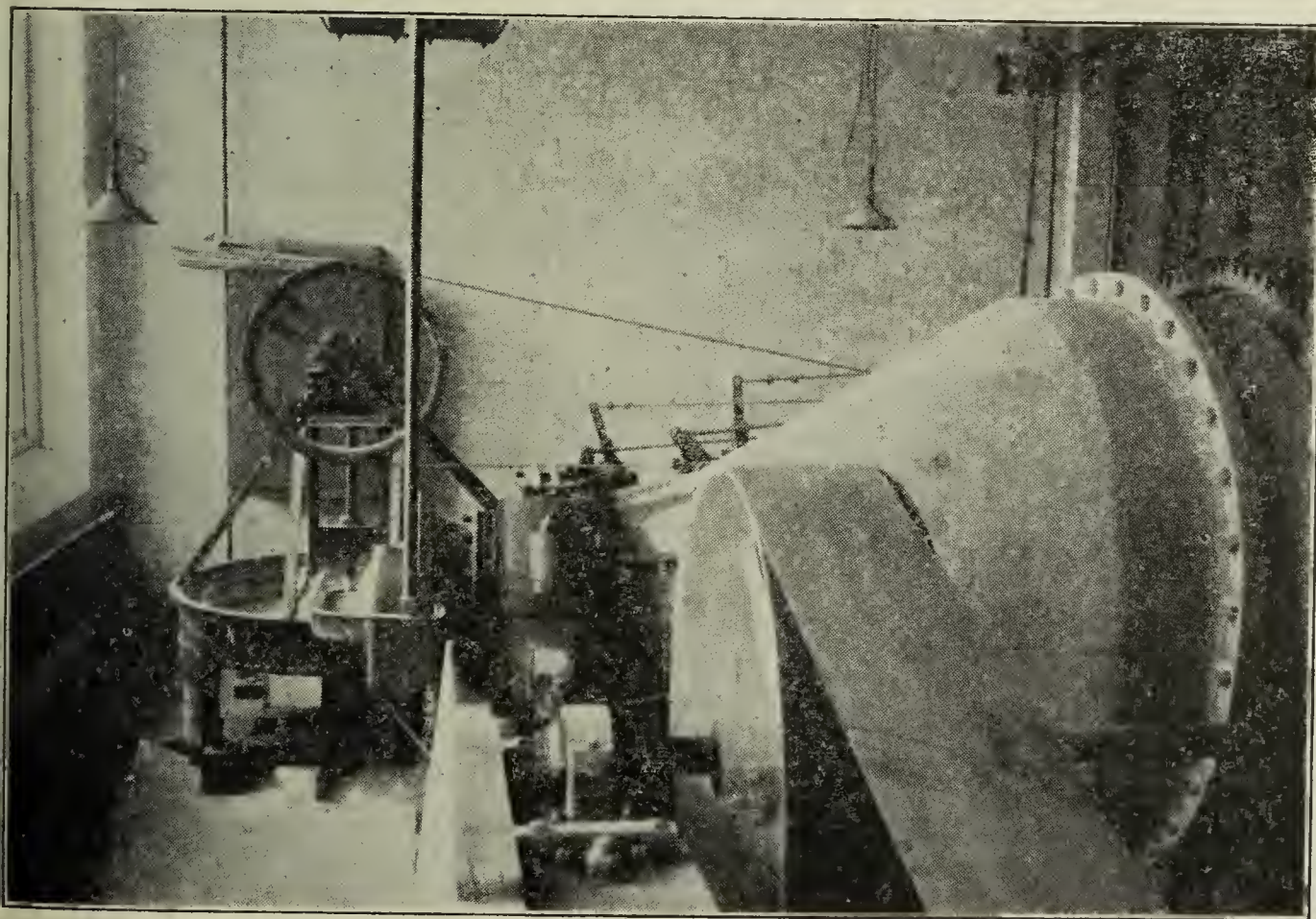


Fig. 13.—Conical Mill operating in "closed circuit" with a Dorr bowl classifier for grinding feldspar by the wet process.

to place a small trommel screen at the end of the mill, or where the capacities are relatively large, to use an outside separating device, the oversize going back to the mill for regrinding; thus the finished product is absolutely uniform containing no coarse pieces. This system eliminates a great deal of the handling and reduces the possibility of foreign substance getting into the finished product. The great advantage aside from the reduction in labor cost is the reduction in power for a given capacity.

One of the largest manufacturers of sanitary ware in the United States is operating an 8-ft. diameter by 30-in. cylinder Conical Pebble Mill in conjunction with a screen, taking the dry quenched frit, at a capacity of 2,000 pounds per hour, or 20,000 pounds per day, reducing the frit to a fineness of 100% through 60-mesh, with about 70% through 200-mesh and requiring 50 h. p. One man easily handles this entire operation and in fact, is free to care for other equipment nearby.

Where capacities of 4,000 pounds or more per day are required, the economies are quite marked as compared with the ordinary batch process.

The accompanying layouts, Figs. 7 and 8, show the systems used. Fig. 7 illustrates how the trommel is connected to the mill for ordinary use and Fig. 8 illustrates the method of operating in conjunction with a vibrating screen for higher capacities and finer products.

Other Materials

There are a number of other materials commonly ground in the ceramic industry which are used more or less extensively, many of which can be and are being ground very economically by the continuous process, but as the method of grinding these other materials is very similar to those already described, with only slight modifications, they will not be taken up in detail at this time.

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THE VALUE OF SCREEN ANALYSIS IN CERAMICS

By F. P. NICKERSON

ABSTRACT

The development of equipment for classifying materials according to size. The importance of classification and proportioning of size of particles in products made from sand and or crushed material.

The advantages in screen analysis, of testing sieves with openings made to a fixed size.

The advantages of logarithmic or direct diagram plotting of screen analysis.

Checking the efficiency and controlling the character of the product obtained from grinding units and checking products whose value is influenced by the size of grain.

Historical Review

Screening, or classification according to size, has been a practice for many centuries, in fact, screening was in vogue when history was recorded in hieroglyphics, and has been definitely referred to by writers in the last two centuries B. C. and the first century A. D., where hides with holes punched through them were used.

Agricola indicates that a considerable improvement has been made in the screening process, in his work "De Re Metallica," written A. D. 1556, wherein he describes the sieve as "a box made out of planks with holes bored in the planks of the bottom or with iron wires stretched both ways across the bottom of the box and fastened at the intersections with small iron clips." At this time woven wire screens were also available.

Three illustrations from the many interesting ones in De Re Metallica, serve to remind us that the road to present sizing facilities has been long and arduous.

In the first illustration (Fig. 1) we see the laborious process employed in Agricola's time, of sizing the material from the stamp mill before consigning it to the smelter.

The crushed ore was carried down through the plant by gravity, one size of particles being retrieved at each screening level and every time a load was dumped at the top of the chute each successive screen operator empties the residue of his screen in a pile beside him and receives a new charge of unclassified material.

The men in the foreground are sieving with the aid of tubs of water.

Fig. 2 shows two other types of screens used in the 15th century.

The figure in the foreground shows a one-man screening machine, the screen being suspended at one end by a rope, the screen fastened to the pole at the other end of the rope and the vibration supplied by the man at the other end of the pole.

In the background is still another type of screen which is suspended in the center and operated by two men.



FIG. 1.

In Fig. 3, Agricola describes this type of sieve as being made of iron wires, hoops and rods.

The operation is continuous as the boy in the picture supplies the screen with the material that is to be washed while the man at the other tub moves that part of the ore that has passed through the sieve. The man at the screen has a regular job.



FIG. 2.

Development of Equipment

The introduction of the steam engine and power driven machinery has been responsible for the gigantic proportions of the present day operations. Notwithstanding their quantity production, each year finds us facing the demands for greater efficiency and exactitude in production in all industries.

In industries using ground or crushed material in the body of their product, which undergoes a cementing or fusing process, the size of the particle

that goes to make up the aggregate of that body plays an important part, not only the largest sized particles that just pass the screen, but the proportion of the varied sized particles that go to make up the total.

Therefore, the need for an accurate device for measuring the size of the grain or particle is obvious.

The testing sieve was the outgrowth of the necessity of measuring the size of particles and also determining the proportions of the various sized particles present.



FIG. 3.

The size of opening, the clear space between the wires, and not the mesh directly determines the size of the product that will pass a testing sieve. For instance, by referring to a wire cloth catalogue, we find that 20-mesh wire cloth is made from sixteen different diameters of wire, ranging from 0.0095 in. to 0.032 in. A 20-mesh sieve made from wire 0.0095 in. in diameter, has an opening 0.0405 in., while a 20-mesh sieve made from 0.032 in. wire has an opening of 0.018 in. When we say "20-mesh" then it means

be any screen with 20 openings to the lineal inch made anywhere from 0.0095 to 0.032 in. wire, with a chance for a variation in the sieve opening from 0.0405 to 0.018 in., a difference of 0.0225 in., so that one person may have 0.018 in. in mind when referring to a 20-mesh screen and another an opening 225% larger or 0.0405 in.

In the United States, it has been the practice to use light or medium grades of wire for testing sieves, while the I. M. M. sieves are made from the heaviest wires it is possible to weave, so that the foregoing is not an exaggerated illustration of the confusion that arises from the use of the term "mesh" in reference to a sieve that is to be used as a standard of measure.

Most manufacturers have given up the use of gage numbers and express the diameter of the wire in the decimal fraction of an inch. Let us take another step in advance and refer to testing sieves by the size of opening in decimal fractions of an inch or millimeters.

Instead of "20-mesh," give the opening, as "0.0328 in. testing sieve;" instead of "200-mesh product," say "0.0029 in. or 0.074 mm. product."

Let us think of our testing sieves as a series of openings. What interests us is that the openings are uniform and accurate, and the wire cloth is double-crimped and made from a suitable diameter of wire, so that the wires cannot shift and get out of place when the sieve is put into service.

When we consider testing sieves as a series of openings, the most important thing to decide is the relationship between these openings. For years those interested in ore dressing and the sizing of products by screens have been using testing sieves with no relationship between the sieve openings, except that the openings either increased or decreased in size. It made a standard of measure without any ratio or relation between the terms of the standard. It was a makeshift, taking whatever meshes and wires could be the most readily furnished.

Fig. 4 shows the openings in the Tyler standard screen scale with a fixed ratio between the openings. This scale is the one with which the most of us are familiar and has as its base an opening 0.0029 in. in diameter—the opening in a 200-mesh screen made of wire 0.0021 in. in diameter, the standard sieve as adopted by the Bureau of Standards of the United States Government—the openings increasing in the ratio of $\sqrt{2}$, or 1.414.

The ratio between the different sizes of the screen scale has been taken as $\sqrt{2}$, or 1.414, as recommended by Rittinger in his work on ore dressing, and the niceness of this will be apparent from the following: taking 0.0029 in. or (0.074 mm.), the opening in the 200 mesh sieve as the base or starting point, the diameter of each successive opening is 1.414 times the opening in the previous sieve.

It also makes the area or surface of each successive opening in the scale just double that of the next finer or half that of the next coarser sieve. In

other words, the diameters of the successive sizes have a constant ratio of 1.414 while the areas of the successive openings have a constant ratio of 2.

Another advantage in this selection of ratio is that by skipping every other screen, the ratio of diameter is 2 to 1; by skipping two sizes the ratio

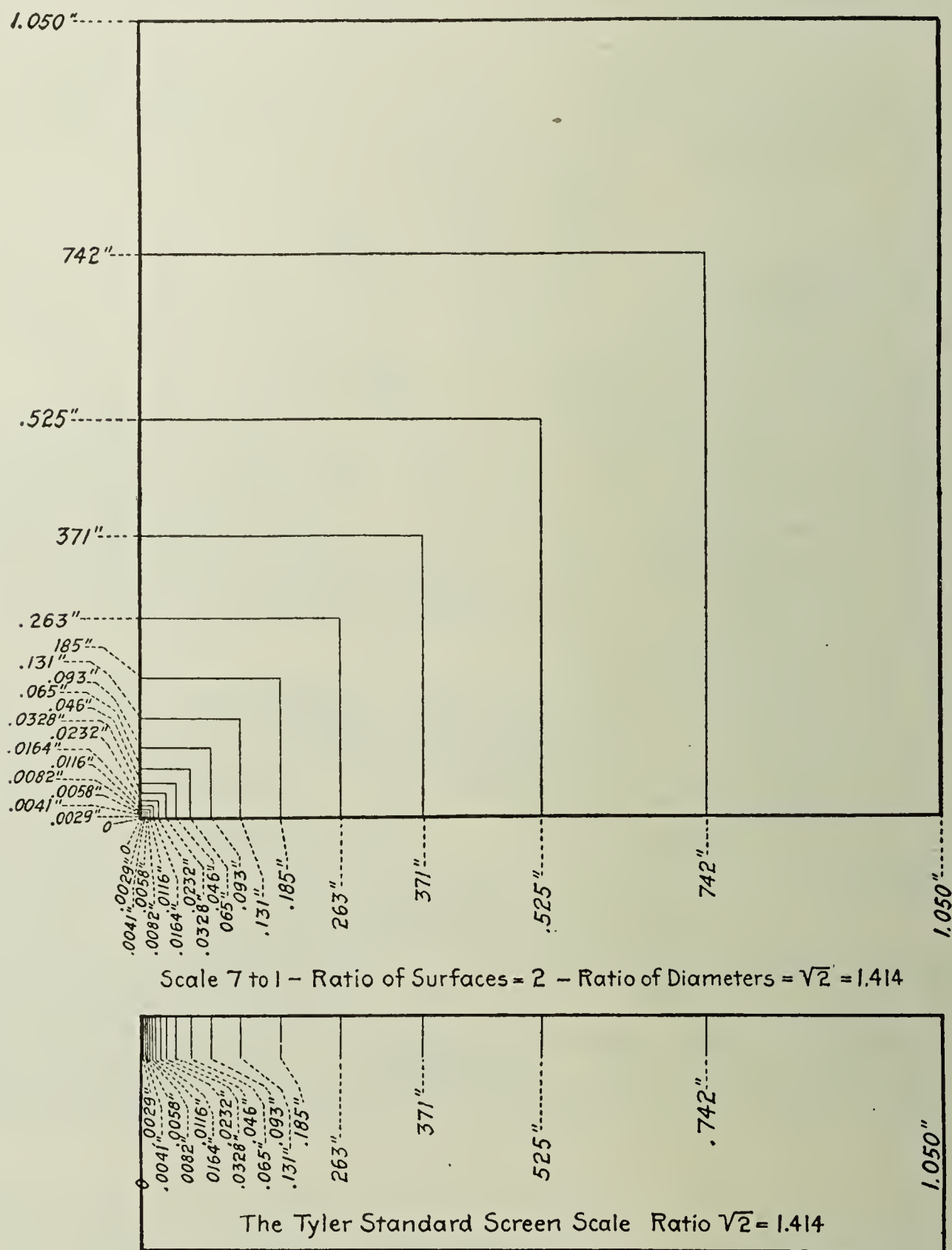


FIG. 4.

is 3 to 1 (approximately); and by skipping three sizes, the ratio is 4 to 1 so that in selecting a screen scale for concentrating work, for instance, one can pick out from the table without any calculation a 1.414, 2, 3, 4-to-1 ratio of opening.

The openings in this screen scale, from 0.0029 in. (0.074 mm.) to 1.050 (26.67 mm.), are shown in Table I, which shows also the mesh and wire that have been used to produce those openings.

The scale can of course be carried further for either finer or coarser screens using the same ratio, but the table covers all the sizes generally used for laboratory work.

In most screen analyses we are more generally interested in the diameter of the various size products, and for this reason we usually think of the scale as a lineal measure. The testing sieve openings are therefore referred to by giving the diameter of the opening instead of its area.

TABLE I
THE TYLER STANDARD SCREEN SCALE

Opening(In. Ratio $\sqrt{2} = 1.414$)	Mm.	Mesh	Diam. of wire, in.
1.050	26.67	...	0.149
0.742	18.85	...	0.135
0.525	13.33	...	0.105
0.371	9.423	...	0.092
0.263	6.680	3	0.070
0.185	4.699	4	0.065
0.131	3.327	6	0.036
0.093	2.382	8	0.032
0.065	1.651	10	0.035
0.046	1.168	14	0.025
0.0328	0.833	20	0.0172
0.0232	0.589	28	0.0125
0.0164	0.417	35	0.0122
0.0116	0.295	48	0.0092
0.0082	0.208	65	0.0072
0.0058	0.147	100	0.0042
0.0041	0.104	150	0.0026
0.0025	0.074	200	0.0021

When it is necessary to carry an analysis finer than 200-mesh, sieves can be supplied as fine as 230-mesh in plain cloth and 325 mesh in twilled cloth.

To provide for a closer sizing where it is necessary in the finer sizes, three intermediate sieve sizes have been added to the screen scale—0.0069 in. (250-mesh), 0.0049 in. (115-mesh) and 0.0035 in. (170-mesh). This produces a screen scale from 0.0029 in. (200-mesh) to 0.0082 in. (65-mesh), the openings in which increase in the series in the ratio of $\sqrt[4]{2}$, or 1.189, the factor recommended by Professor Richards in his work on ore dressing, or the square Rittinger Ratio. This ratio of diameter or 1.189 makes a difference in the areas between these sizes of about 1.5 times instead of 2 as in the other scale. Table II shows the sieve openings for the closer classification where the ratio is $\sqrt[4]{2}$.

TABLE II
RATIO $\sqrt[4]{2}$ or 1.189

Opening (Ratio $\sqrt[4]{2} = 1.189$) In.	Mm.	Mesh	Diam. of wire
0.0082	0.208	65	0.0072
0.0069	0.175	80	0.0056
0.0058	0.147	100	0.0042
0.0049	0.124	115	0.0038
0.0041	0.104	150	0.0026
0.0035	0.088	170	0.0024
0.0029	0.074	200	0.0021

Not only do the screen scale sieves divide a product in much better proportion than a sieve series without any relationship between the open

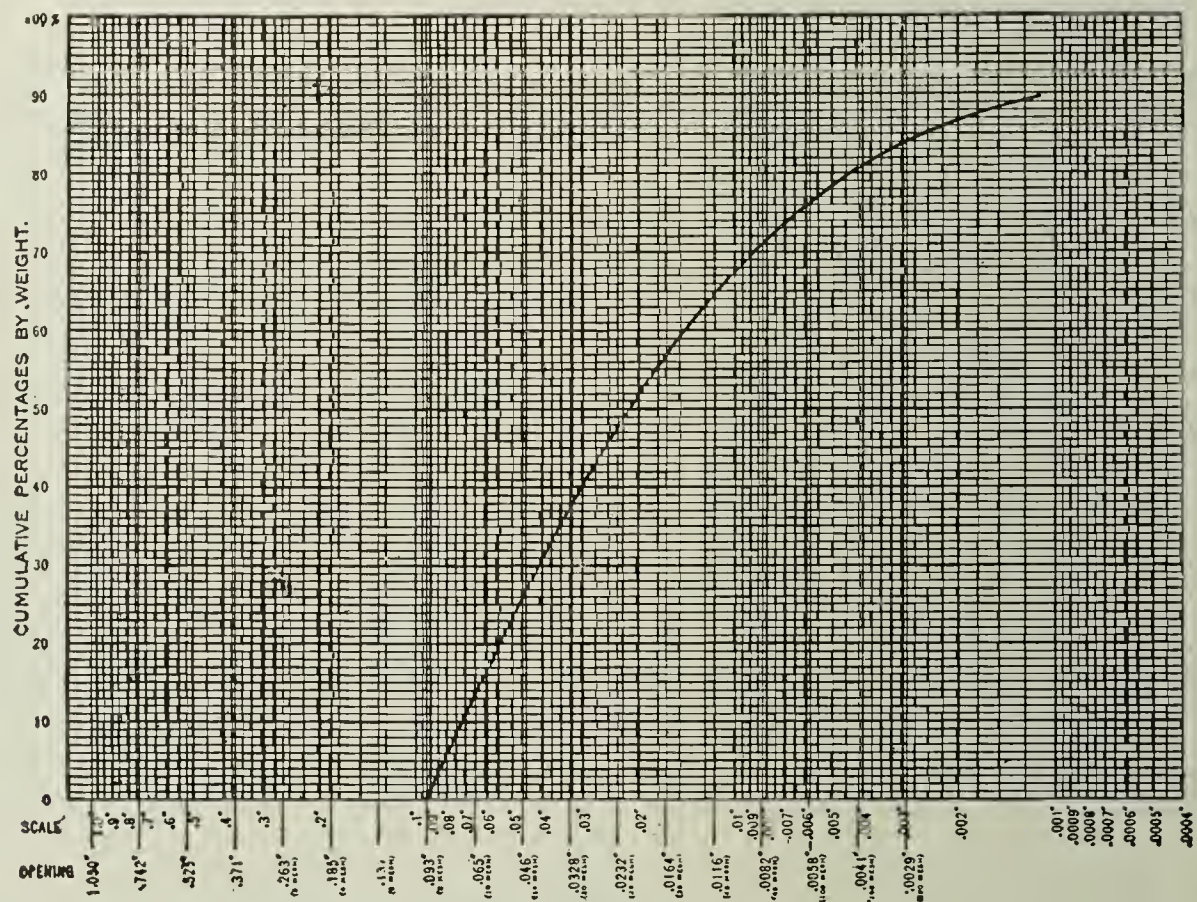


FIG. 5.—Cumulative logarithmic plot.

ings, but the results of the screen analysis can be represented by a plotted curve to much better advantage.

There are many advantages in the graphic method of illustrating the data obtained in a screen analysis. Plotted curves of the crushings by different methods or from two competing machines, for instance, express the difference in a more striking and concise manner than do the tabulated data. Of the several methods of plotting these curves, the cumulative direct plot and cumulative logarithmic plot are the two most valuable and generally used.

The curves by either method are plotted by marking the cumulative percentages of the material which remain on the sieves as ordinates

vertical lines drawn from the several corresponding openings on the horizontal scale of the diagram.

After drawing in the curve, the percentages remaining on any set of openings other than those of the testing sieves used can be found by interpolation and in this way the redistribution of the same material by any assumed set of openings can be determined without having sieves of those openings. By cumulative percentage is meant the total amount of the product which would remain on a testing sieve if only one sieve were used for testing the whole sample, so that to get the cumulative weight, it is necessary to add all of the material which remains on sieves coarser than the one in question to the amount remaining on that sieve. In other words, each point on a cumulative plot represents the total material that would be retained if only the one sieve represented by that particular point were used in the analysis.

Table III represents a screen analysis showing the percentages and cumulative percentages shown in the Cumulative Logarithmic Plot in Fig. 5.

TABLE III
SCREEN ANALYSIS SHOWING CUMULATIVE PERCENTAGES
SCREEN-SCALE RATIO 1.414

	Openings		Mesh diam.		Sample wts., gram	Weights, per cent	Per cent cumulative wts.
	Mm.	In.	wire, in.				
Indicate the screen crushed through and also first retaining screen	26.67	1.050	...	0.149	...	...	...
	18.85	0.742	...	0.135	...	...	...
	13.33	0.525	...	0.105	...	...	...
	9.423	0.371	...	0.092	...	...	...
	6.680	0.263	3	0.070	...	...	...
	4.699	0.185	4	0.065	...	...	...
	3.327	0.131	6	0.036	...	...	...
pass	2.362	0.093	8	0.032	...	...	...
retained on	1.651	0.065	10	0.035	70.0	14.0	14.0
	1.168	0.046	11	0.025	60.0	12.0	26.0
	0.833	0.0328	20	0.0172	50.0	10.0	36.0
	0.589	0.0232	28	0.0125	55.0	11.0	47.0
	0.417	0.0164	35	0.0122	50.0	10.0	57.0
	0.295	0.0116	48	0.0092	35.0	7.0	64.0
	0.208	0.0082	65	0.0072	30.0	6.0	70.0
	0.147	0.0058	100	0.0042	32.5	6.5	76.5
	0.104	0.0041	150	0.0026	20.0	4.0	80.5
	0.074	0.0029	200	0.0021	17.5	3.5	84.0
ss	0.074	0.0029	200	0.0021	80.0	16.0	
					500.0	100.0	

Fig. 6 shows a cumulative direct plot of the screen analysis given in Table . This form of direct plotting is unique, since all crushings, to whatever e, are expressed on diagrams of the same uniform dimensions and having

the same length of base line. This renders a comparison of the curve from various crushings more comprehensive than when diagrams with varying lengths of base line are used.

The vertical lines on the diagram represent any given set of sieve openings having a constant ratio of 1.414, the first left-hand vertical representing the screen opening through which the sample has all been crushed, and the last or extreme right-hand vertical, representing zero. The curves, therefore, start at the lower left-hand corner and terminate at the upper right-hand one.

To illustrate the usefulness of the plotted curve, let us take an illustration from actual practice. Given a sample of concentrator mill heads which are the undersize of Hum-mers Electric Screens equipped with 3-mesh

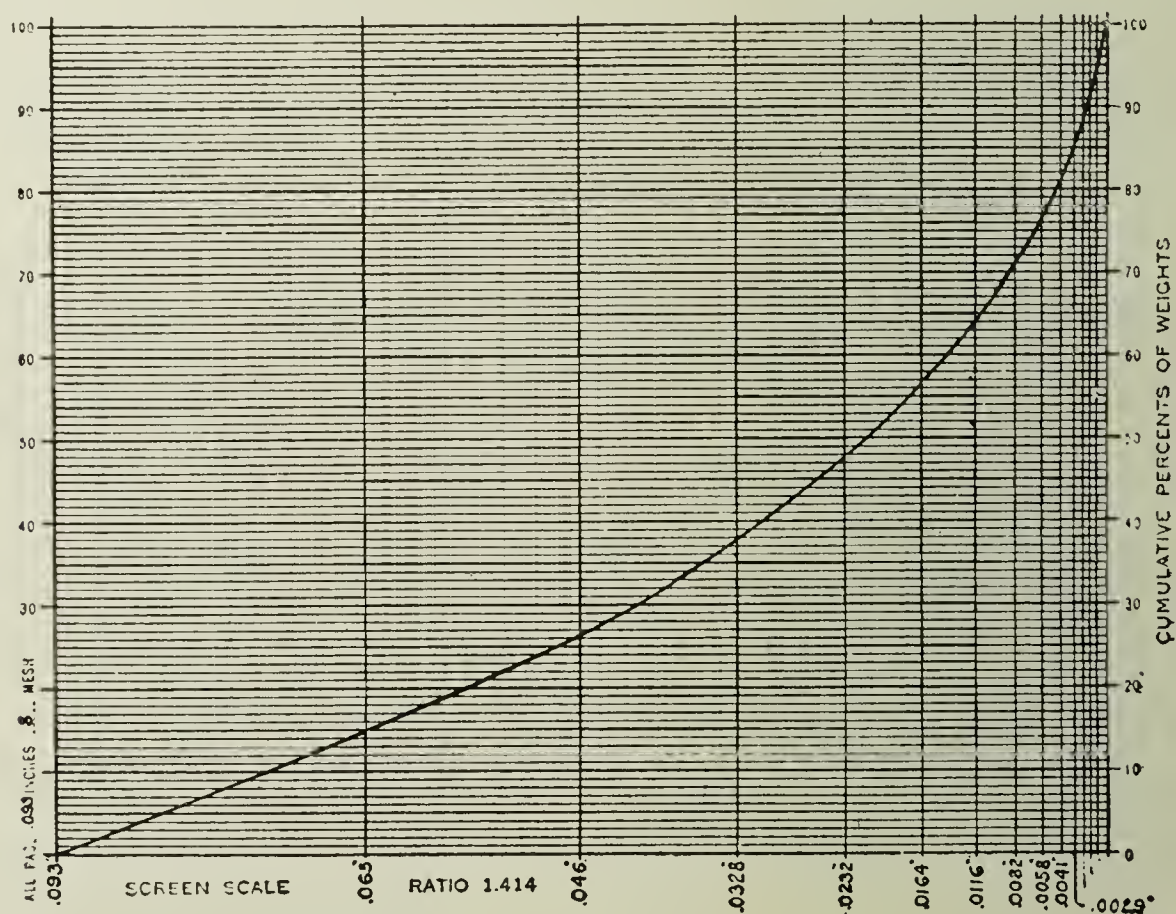


FIG. 6—Cumulative Direct Plot.

0.148 in. wire, opening 0.158 in. According to the arrangement of the mill these mill heads pass successively through three sets of Hum-mers, the oversize of which is delivered to three sets of jigs, while the undersize of the last screen passes to tables and vanners. With the last of the three screens equipped with 12-mesh, 0.047 in. wire, opening 0.036 in., with what size screen openings should the other two screens be equipped to divide the jig product evenly by weight between the three sets of jigs?

The screen analysis of the product passing the 3 mesh, 0.148 in. Hum-mers is shown in Table IV. It has only been carried as fine as the 0.003 in. (100-mesh) sieve, since we are not interested in the fines which go to the tables.

TABLE IV
SCREEN ANALYSIS OF CONCENTRATION MILL HEADS
SCREEN-SCALE RATIO 1.414

	Openings		Mesh diam.		Sample	Weights,	Per cent
	Mm.	In.	wire, in.		wts.,	per cent	cumula-
					gram		tive
indicate the screen crushed through and also first retaining screen	26.67	1.050	...	0.149	...	...	...
	18.85	0.742	...	0.135	...	...	...
	13.33	0.525	...	0.105	...	...	...
	9.423	0.371	...	0.092	...	...	...
	6.680	0.263	3	0.070	...	...	...
1 pass	4.699	0.185	4	0.065	...	...	...
	3.327	0.131	6	0.036	253	12.65	12.65
	2.362	0.093	8	0.032	264	13.2	25.85
	1.651	0.065	10	0.035	262	13.1	38.95
	1.168	0.046	14	0.025	155	7.75	46.70
retained on	0.833	0.0328	20	0.0172	132	6.65	53.35
	0.589	0.0232	28	0.0125	126	6.3	59.65
	0.417	0.0164	35	0.0122	94	4.7	64.35
	0.295	0.0116	48	0.0092	83	4.15	68.5
	0.208	0.0082	65	0.0072	66	3.3	71.8
1 pass 0.0058 in.	0.147	0.0058	100	0.0042	64	3.2	75.0
					500	25.0	
					2000	100.0	

totals

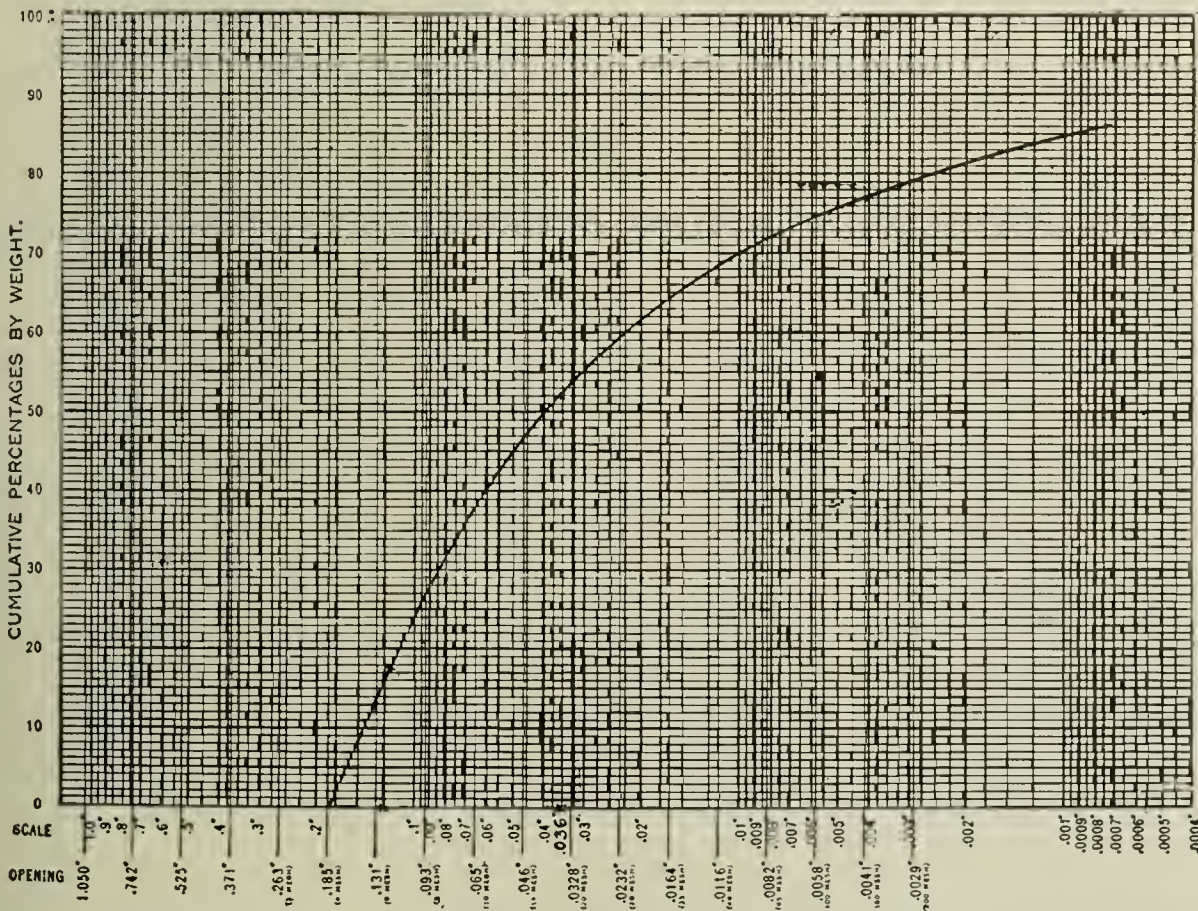


FIG. 7.—Curve showing screen analysis of concentrator mill heads.

After plotting the curve (Fig. 7), showing this screen analysis, we find that at the opening 0.036 in. (the 12-mesh, 0.047 in. wire on the last screen) we retain 52.5% of the product, which is the amount to be divided equally

by weight between the three sets of jigs. One third of this amount 17.5%. By finding the point on the curve representing 17.5% of the product, we see that this part of the material will be retained by an opening of 0.125 in.; the position of the point on the curve representing 35% of the product indicates that an opening of 0.0725 in. will retain

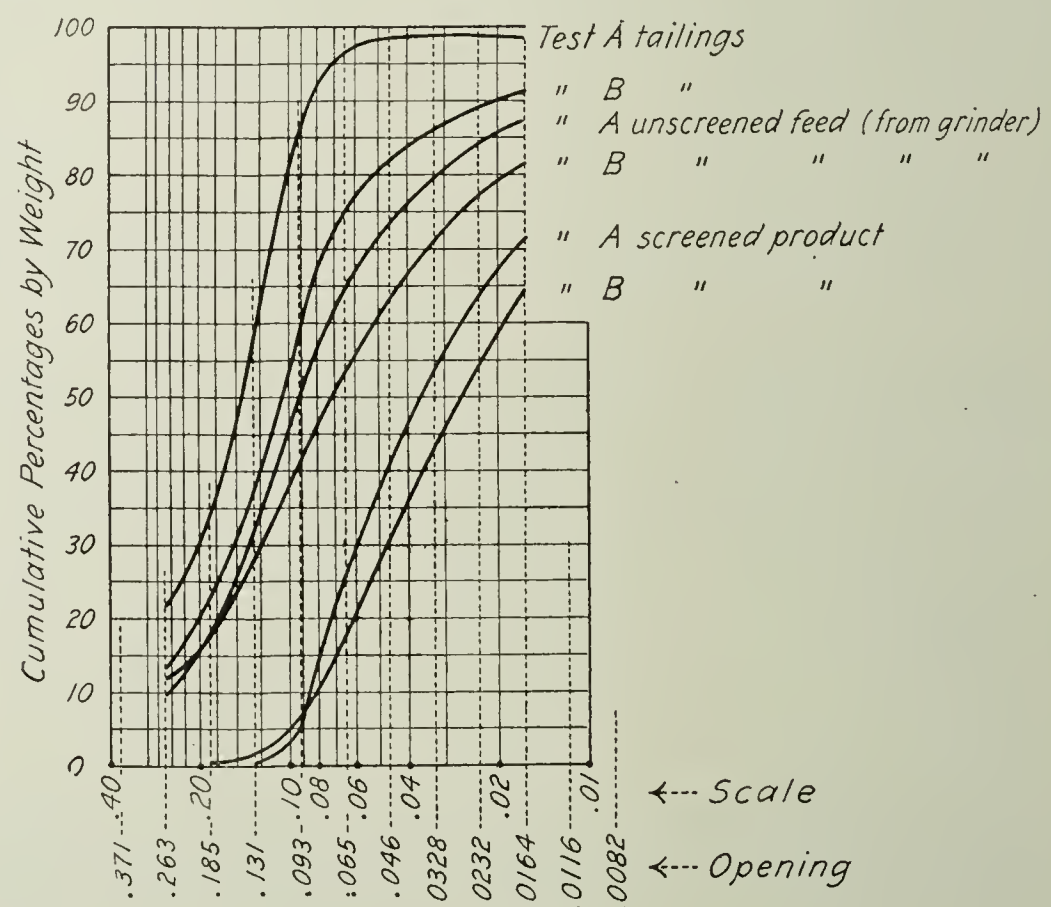


FIG. 8.

Screen scale ratio 1.414			Product being ground and separated					
Size hole	Mesh	Dia. wire	Talling Test A	Talling Test B	Unscreened feed Test A	Unscreened feed Test B	Screened product Test A	Screened product Test B
.263"	3	.070"	21.4%	13.0%	11.3%	9.8%	0.0%	.0%
.185	4	.065	11.6	9.6	6.2	7.2	.0	.1
.131	6	.036	25.8	15.6	14.9	10.3	.1	1.1
.093	8	.032	24.6	20.4	17.5	12.8	5.8	5.1
.065	10	.035	13.2	16.4	14.8	13.9	19.3	10.3
.046	14	.025	1.7	7.5	8.3	9.5	16.2	13.5
.0328	20	.0172	.4	3.5	5.6	6.3	11.2	11.9
.0232	28	.0125	.1	3.0	5.1	6.4	10.3	10.7
.0164	35	.0122	.1	2.1	4.1	5.1	8.3	11.0
Passing	35	(Finer)	1.1	8.9	12.2	18.7	28.8	36.3
Totals			100	100	100	100	100	100

that percentage of the product. Therefore, to divide the product equally on the three jigs the first screen must be covered with a cloth that will retain the 0.125 in. part of the ore, and the second screen with a cloth that will retain the 0.0725 in. part of the ore. It is then an easy matter to select the required style of cloth to produce this result.

It is easily seen how this would apply to any distribution of sizing and for any purpose.

Figure 8 shows the results obtained through screen analysis on a heavy clay products plant, in operation in Ohio. The cumulative per cent was

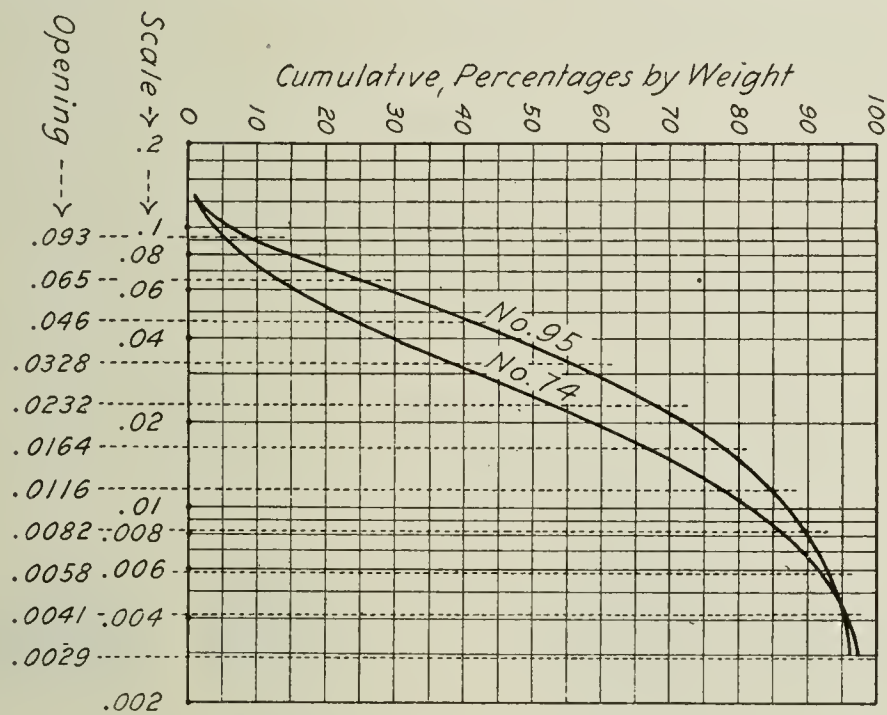


FIG. 9.

Indicate the screen crushed through and also first retaining screen	Screen scale ratio 1.1414		Mesh	Diameter wire, inches	No. 74 per cent	Cumulative per cent	No. 95 per cent	Cumulative per cent
	Inches	Milli- meters						
.....	1.050	26.67	...	.149	....	....	....	....
.....	.742	18.85	...	.135	....	....	....	....
.....	.525	13.33	...	.105	....	....	....	....
.....	.371	9.423	...	.092	....	....	....	....
.....	.263	6.680	3	.070	....	....	....	....
.....	.185	4.699	4	.065	....	....	....	....
.....	.131	3.327	6	.036	.8	.8	.8	.8
.....	.093	2.362	8	.032	4.0	4.8	7.6	8.4
.....	.065	1.651	10	.035	8.3	13.1	16.8	25.2
.....	.046	1.168	14	.025	11.0	24.1	16.4	41.6
.....	.0328	.833	20	.0172	13.8	37.9	14.2	55.8
.....	.0232	.589	28	.0125	16.4	54.3	12.3	68.1
.....	.0164	.417	35	.0122	12.0	66.3	9.7	77.8
.....	.0116	.295	48	.0092	10.0	76.3	6.3	84.1
.....	.0082	.208	65	.0072	9.4	85.7	5.9	90.0
.....	.0058	.147	100	.0042	6.4	92.0	4.8	94.8
.....	.0041	.104	150	.0026	3.7	95.8	2.2	97.0
.....	.0029	.074	200	.0021	1.4	97.2	1.0	98.0
ass. ....	.0029	.074	200	.0021	2.8	100.	2.0	100.
.....
Totals					100		100	

ft out of the table, but is plotted in the cumulative logarithmic plot just above. (See Fig. 5.) The grinding unit consists of a battery of dry pans preceded by a crusher.

They found through screen analysis that the proportioning of the aggregate of the body of this product played an important part in influencing the resistance of their brick in the abrasion test. By extending the analysis so as to cover the entire operation, that is, taking samples of the fines that were being retrieved from their screens, samples of the circulating load that were going to the screen from the dry pans, and samples of the tailings being returned to the dry pan, an efficiency factor was obtained, and having learned the proportions desirable, they found that it could be gotten by making some changes in their screening equipment and holding to a given size opening in their dry pan plates.

Incidentally, by efficient screening methods, the proportions given in the analysis in Figure 8 were maintained very closely, irrespective of the varied water content in the material. The plant has been in operation a number of years and an improvement in the quality of their product



FIG. 10.

amounting to a greatly decreased loss and a rare uniformity in their rattle test have been their reward for nearly two years since going from guess work methods to pre-determined mixtures.

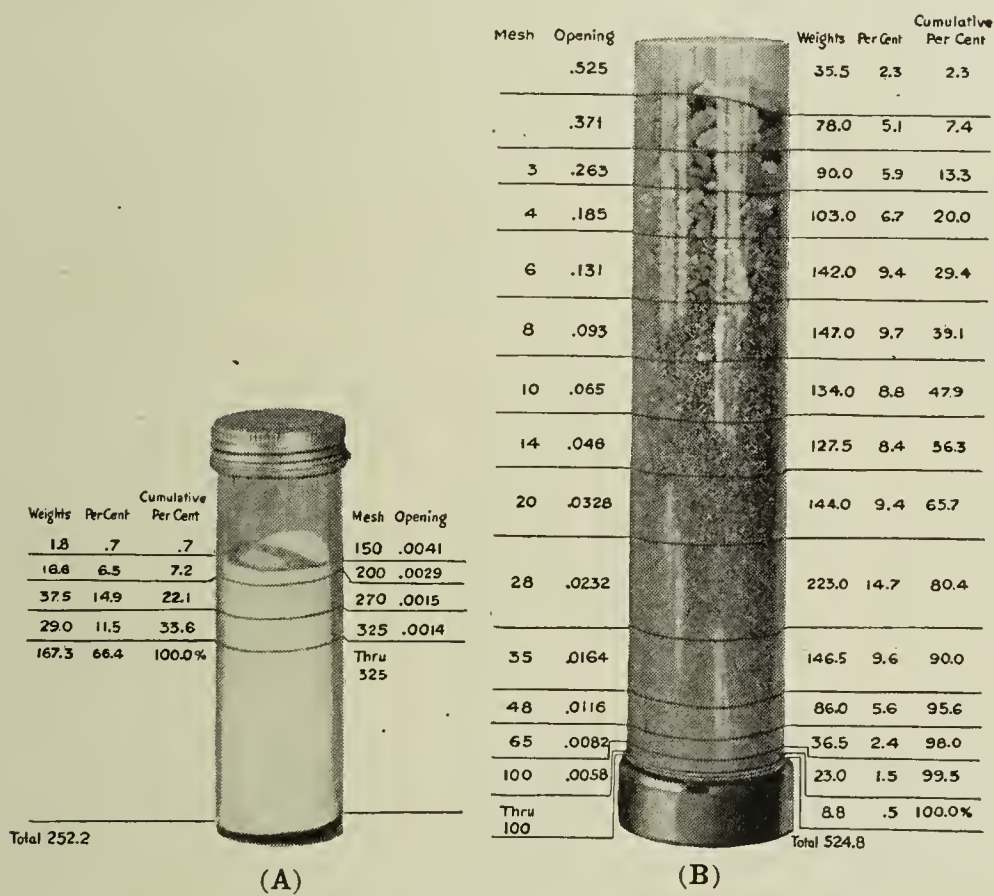
Figure 9 illustrates a cumulative logarithmic plot of an inefficient and subsequently efficient screening operation of the products of a dry pan. You will observe an improvement in their separation amounting to as much as 8% of the total fines retrieved on a single sieve was obtained by changing their screening equipment without changing any features of their grinding unit or abandoning the size of the particles constituting the aggregate.

Figure 10 illustrates this same analysis in volume. You will observe that the first bottle is full and represents 100% of the product from their dry pan. The bottle containing the larger proportion, 59% full, represents the retrieved fines of the 74% efficiency separation, while the other bottle which is 41% full, represents the tailings of this same operation.

It was decided that the quality of their product would be improved and higher tonnage retrieved at a lower cost if they instituted a better screening program.

The two bottles indicated as 95% separation show the result and incidentally increased the grinding capacity of this particular unit more than 20%. However, the proportioning of the aggregate of their material was the incentive for screen analysis.

The smaller tube (Fig. 11-A) shows the product of a commercial operation on feldspar ranging from 150-mesh (0.0041 in.) to 325-mesh (0.0014 in.) and finer, classified with the $\sqrt[4]{2}$ series of sieves.



ANALYSIS EXPRESSED IN VOLUME

FIG. 11.—Classification of sizes.

The contents of the large tube (Fig. 11-B) represent the product of a grinding unit ranging from 0.525 in. to 0.0058 in. or 100-mesh, classified by sieve whose ratio is 1.414 or $\sqrt{2}$.

Recently in checking the efficiency of a grinding installation consisting of three different types of grinders, from which a 35-mesh product was desired, we found that two of the grinders were delivering practically the same tonnage at 10- and 14-mesh while at 35-mesh and finer, one was delivering two and a half times the tonnage of the other grinder.

After learning these facts, it was a simple matter to use the two machines in closed circuit in the order in which they were best qualified to serve and increase the tonnage to a point nearly equal the efficiency of the hitherto best producing mill.

In conclusion, to those who are familiar with the characteristics of rocks of various geological eras, to those who realize that the various components of the product undergoing mechanical disintegration is offering an equally varied resistance and leaves its evidence in size proportions; to those who would bring about certain chemical reactions by design of a predetermined temperature application; to those who would know the efficiency of their grinding and screening plants, or who would maintain a standard of quality where the size and proportion of grain wield an influence as there is a value to the mariner in his compass, to the carpenter in his square or a designing process value to any artisan who would not trust the building of his efforts to the specifications of guess, imagination and opinion, so is there a *value to screen analysis in ceramics*.

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ORIGINAL PAPERS

TESTS ON THE RESISTIVE QUALITIES OF SODA-LIME GLASSES TO WATER¹

BY L. A. PALMER

ABSTRACT

A quantitative determination of the amount of alkali taken into solution after exposure for six hours to boiling water was made with a large number of soda-lime glasses.

Method.—The alkaline solution obtained after the six-hour treatment was titrated with 0.01 *N* H₂SO₄ until complete absence of color with either Phenol-Red or Bromthymol-Blue used as indicator.

A volume of the dilute acid equal to twice the volume required to destroy the color was then added, the solution was boiled twenty or thirty minutes and then titrated back to faint appearance of color with 0.01 *N* NaOH. The two indicators were used more or less interchangeably and with equally good results.

Relationship between Composition and Resistance to Water.—Various American bottles were studied. It was found that these glasses varied considerably in resistance to water and in composition. With respect to composition, the actual analyses having been computed to molecular percentage composition, the numerical magnitude of the reactivity coefficient (Zulkowski's formula), was found to be in general agreement with the number of cc. of 0.01 *N* alkali taken into solution during the six-hour test. The ratio of soda to combined lime, magnesia and alumina, all expressed in molecular percentage, was likewise larger in the case of glasses least resistant and diminished as the resistance of the glass to the solvent action of water increased. Glass of composition such that this ratio was less than 1.6 was found to have excellent resistant properties.

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Introductory

The work outlined in this paper is a continuation of that published by A. E. Williams¹ of the Bureau of Standards. Some significant facts were observed by him as regards the factors affecting the durability of glass articles in service. The purpose of these investigations has been to study the qualities of various types of American glassware and to devise standard methods of testing them. Under the direction of Mr. Williams I have undertaken to develop a simple method of measuring the resistance of various types of American glassware and from such data to study and compare them. The method consists in determining the amount of alkali taken into solution by the chemical action of boiling water on the finished glass article. From data compiled by Foerster² it is shown that while the amount of alkali taken into solution by water does not show the total matter in solution yet it does show that a determination of this alkali will give a fair means of judging the comparative resistances of glassware.

Since it has been found that the quantity of alkali in solution after sterilization or after a long period of storage is appreciable in the case of glasses of low resistance, and that this quantity is more dependent upon the composition of the glass than upon any other factor, the importance of having some quick and simple means of testing the resistance of glassware can easily be seen.

Previous Work

The resistance of various types of chemical glassware to the action of water has been thoroughly investigated by P. H. Walker and F. W. Smither of the Bureau of Standards. In obtaining a method applicable to all types and sizes and shapes of ordinary soda-lime glassware, it has been necessary to have in mind the difference in the purpose of making the tests from that of testing glass for laboratory use. Mylius, Foerster and Kohlraush⁴ offer several methods, but none of them meets with that requirement of simplicity which it was our purpose to attain.

Treatment of Sample

Tests by many investigators have been made on broken samples. The difficulty of obtaining particles of even nearly uniform area and size can easily be seen, and furthermore it is simpler to make the test on the finished article. Such a test involves all factors, surface conditions of the original article as well as composition.

¹ A. E. Williams, "Disintegration of Soda-Lime Glasses," *Jour. Amer. Ceram. Soc.* **5**, 8 (1922).

² *Z. anal. Chem.*, **33**, 381.

³ "Comparative Tests of Chemical Glassware," by Percy H. Walker and F. W. Smither, Bureau of Standards, *Tech. Paper* **107**. "Chemical Glassware," Percy H. Walker, *Jour. Am. Chem. Soc.*, July, **1905**.

⁴ Hovestadt, "Jena Glass," Pages 318-371 (Review this work).

Broken fragments treated from 6 to 48 hours in boiling water showed considerable disintegration and flaking on the edges, whereas the surfaces were not always visibly etched or chipped. Also after drying, the edges showed a heavy white fringe as compared to slight dimming of the finished surface. This indicates that there is a distinct difference in the rate of disintegration between fractured surfaces and the original finished surfaces of the article. That there is such a difference seems to be a matter of doubt on the part of Turner¹ and his co-workers and our observations seem not to be quite in agreement with his. On account of such differences in degree of disintegration and because of the fact that the resistance of the finished article is of most importance, all tests were made on unbroken samples.

No attempt to duplicate the work of Mylius,² in which he applied the eosin reaction" to freshly broken surfaces, was made for this same reason. The finished article, whether hand molded or machine molded, is the thing of importance. A study of the disintegration rate of the finished article is necessary in order to discover the extent of all possible factors in their effect upon the resistant properties. Our observations are by no means complete, yet they show certain things of interest and if followed up and applied more extensively may lead to conclusions of much greater value than those so far obtained.

Glass which showed the highest rate of disintegration in such an accelerated test as in boiling water for a period of six hours showed a correspondingly high rate when filled with distilled water and kept at room temperature for a period of six months, so that the six-hour test enables one to ascertain the probability of discoloration or deterioration of the contents of glass container. The rate of disintegration in boiling water was found, however, to be much higher than in water at a temperature even slightly below boiling. It was also found that by partially filling the container to a mark and keeping it there the titration values obtained were not consistent. It is therefore necessary to expose the entire surface to the boiling water and when this is done results are consistent. It having also been observed that six hours in boiling water produced enough soluble alkaline material to make a quantitative determination practicable even in the case of soda-lime glasses, it was decided that that length of time was sufficient for all purposes.

Preparation and Standardization of Reagents

The titrations were made with 0.01 N H_2SO_4 and 0.01 $NaOH$. These solutions were prepared by diluting 0.1 N solutions to ten times their

¹ "Examination of Methods Used in Determining the Durability of Glass," W. E. S. Turner, *Jour. Soc. Glass Tech.*, **6** [21], 30 (1922).

² "Die Eosinreaktion des Glases an Bruchflächen," *Z. anorg. allgem. Chem.*, **55**, 233 (1907), and **67**, 200 (1910).

original volumes. The 0.1 *N* NaOH was standardized against fused benzoic acid¹ and the 0.1 *N* acid was checked against the alkali solution. The alkali solution was kept in Pyrex glass flasks. The indicators used in the method finally adopted were Brom-Thymol-Blue and Phenol-Red. The choice of a suitable indicator was important. Consistent results were not obtained with phenolphthalein, which has a *pH* range of 8.3 to 10. The 0.02% solutions of the sodium salts of Brom-Thymol-Blue and Phenol-Red were used more or less interchangeably and with equally good results. The *pH* range of the Brom-Thymol-Blue solution is 6.6 to 8.28 and that of the Phenol-Red 6.6 to 8.2. The point of neutrality being very close to 7.0, it can be seen that both indicators should be suitable. The choice of either one or the other can be left to the analyst, it merely being a choice of color.

Preliminary Treatment

The glass articles were filled with or immersed in (as in the case of tumblers), distilled water at room temperature for a period of 24 hours. They were then rinsed and washed thoroughly and tested immediately.

Methods of Conducting the Six-Hour Boiling Test

(a) **Method Used for Tumblers or Small Wide-mouth Articles.**—After the preliminary treatment the article is placed in a two-liter Pyrex beaker, Griffin type, and immersed completely in distilled water to a mark on the beaker. The volume of boiling water is kept constantly at this mark by small additions of water. The addition of a considerable quantity lowers the temperature below boiling and this must be avoided. The beakers are covered over at the top with round bottomed Pyrex flasks partially filled with water. This tends to limit the frequent addition of water and also keeps out dust particles. Blank tests are made on the beakers by repeated boiling for six-hour periods until finally no traces of alkalinity can be obtained.

(b) **Method Used for Bottles.**—The bottles are first given the usual preliminary treatment. They are then filled with distilled water at room temperature to a mark such that on increasing the temperature to boiling, they are filled very nearly to the neck. The bottles are then placed upright in a bath of CaCl_2 solution (boiling point 103.5 to 104°C) and held in place by a board rack, the latter placed horizontally and close to the surface of the bath. The necks of the bottles project through holes in the rack. A constant volume of boiling water within the bottle is maintained by passing a current of steam through Pyrex capillary tubing into the bottle to offset loss from evaporation. The steam apparatus is so adjusted that

¹ "Benzoic Acid as an Acidimetric Standard," George W. Morey, Bureau of Standards, *Sci. Paper* 183.

the rate of flow of steam into the bottles is controlled. At the end of six hours the bottles are quickly removed, their contents transferred to Pyrex flasks and titrated.

Methods of Titrating

Several methods were tried. The chief difficulty met with was due to the material in the solution being more or less converted into carbonates. Chemists generally realize the difficulty of titrating dilute carbonate solutions.

The solutions are titrated while hot with the 0.01 *N* acid until colorless, using either Brom-Thymol-Blue or Phenol-Red as indicator. An excess of the acid equal to twice the volume required to destroy the color is then added and the solution is boiled for twenty minutes. This should decompose all carbonates present. The solution is then titrated back to faint alkaline color with the 0.01 *N* NaOH.

In Table I are typical results as obtained by the titrations of solutions from milk bottles after boiling in the manner described above. These bottles came from the same furnace and machine and were made during the same working portion of the day.

TABLE I

No. of bottle	Vol. solution, cc.	Indicator	Total alk. cc. of .01 <i>N</i> NaOH	Alkalinity per 100 cc. of sol. Cc. .01 <i>N</i> NaOH
1	886	Brom-Thymol-Blue	60.9	6.85
2	880	"	55.5	6.30
3	860	"	60.0	6.98
4	860	Phenol-Red	57.8	6.72
5	848	"	59.8	7.05
6	844	"	57.9	6.85
7	850	"	52.4	6.16

An analysis of the solutions obtained by boiling four tumblers of the same type for 32 hours was made. The four solutions were evaporated to small volumes, combined and titrated. An excess of acid was added, the combined solutions were evaporated and the residue was analyzed. The amount of Na₂O given under "dissolved material" has been corrected for the Na₂O added during titration.

Following are the results obtained:

Analysis of glass		Analysis of dissolved material	
	Per cent	Percentage of total	Gm.
SiO ₂	72.10	39.68	0.1090
Na ₂ O	20.54	57.30	0.1574
CaO	4.28	2.07	0.0057
MgO	2.88	0.19	0.0005
Al ₂ O ₃ } Fe ₂ O ₃ }	0.20	0.77	0.0021
Total			0.2747 Gm.

Calculating the weights of Na_2O , CaO and MgO to their equivalent in terms of cc. of $N/10$ HCl , a total of 53.09 is given. The actual titration value obtained was 52.1 cc. $N/10$ HCl .

Tests were made on a large number of beverage, catsup and vinegar bottles. These bottles were grouped in pairs, each one of a pair being identical in make, size, shape and tests made. If one of a pair showed a high rate of disintegration during the six-hour test, the other bottle showed a correspondingly high rate when filled with distilled water and stored at room temperature for a period of six months and two of a pair when given the six-hour test invariably gave alkalinity values that checked closely. Some of the results obtained are shown in Table II.

TABLE II

Bottle no.	Alkalinity per 100 cc. 6 hours.	Alkalinity per 100 cc. 6 months' storage.	Composition of bottle				
	Cc. of .01 N NaOH	Cc. .01 N NaOH	SiO_2	R_2O_3	CaO	MgO	Na_2O
65	8.36	1.97	74.34	0.52	7.02	0.22	17.90
50	4.62	0.90	73.56	1.80	6.58	1.24	16.82
147	3.53	0.49	72.80	1.62	7.90	0.68	17.00
31	1.94	0.14	74.96	1.08	8.07	0.24	15.65
19	5.0	1.20	75.73	0.78	5.18	3.48	14.83
20	6.4	1.48	77.70	1.27	6.23	0.84	13.96

A number of the bottles which were given the six-hour boiling test were analyzed. This number included those which showed the highest rate of disintegration, those most resistant, and some of the "medium" ones. In Table III are given the molecular percentage compositions as calculated from the analyses, the "solubility numbers," which are the number of cubic centimeters of 0.01 N NaOH found present in 100 cc. of the solution after the test, and two series of numbers calculated from empirical formulas in an attempt to relate composition with resistance to water. The results are arranged in order of the magnitude of the solubility numbers, the first ten having the highest solubility numbers and being therefore the least resistant of all the group, and the last eight being the most resistant and least soluble.

In the formula, $\left(\frac{c-d}{c+d}\right)(c+d-3b)$, c represents the molecular percentage of lime and magnesia, d the molecular percentage of soda and the alumina. This is the well known Zulkowski formula as modified by Baillie.¹ The formula is mathematically derived, the derivation being

¹ An examination and extension of Zulkowski's theory of the relation between composition and durability of glasses by William Learmonth Baillie, *Journal Society of Glass Tech.*, 6, No. 21, May, 1922. (See next page for balance of footnote.)

based on the assumption of the presence of simple and complex silicates in the glass. According to Zulkowski's theory a glass is less durable accordingly as the simple silicate content is increased. The complex silicates are not attacked to any extent by water. The above formula therefore represents the molecular percentage of simple silicates. While the experimental work outlined in this paper was not performed with the purpose of verifying any theory, it was seen, however, that the formula is generally in agreement with actual analytical results. The higher the value obtained from this formula, the less durable should be the glass and this was found to be so in most cases. A few variations are noted among the bottles that are of nearly equal resistance, for example, Nos. 6 and 7 are higher than 4 or 5 and Nos. 13, 14, and 21 are much higher than glasses equally resistant.

The mol. percentage of CaO + mol. percentage MgO , bottle No. 1, Table III, = 9.89 mol. percentage of RO . Designating the mol. percentage of SiO_2 (or RO_2), by a , Al_2O_3 by b , RO by c and R_2O by d and substituting these values in the reactivity coefficient, $\frac{c - d}{c + d} (c + d - 3b)$, we obtain the negative value, -9.56 . The numerical value of this quantity is considered without regard to the sign, that is, glass which as a reactivity coefficient of -9.56 is less durable than glass No. 11 which gives

¹ In applying Baillie's extension of Zulkowski's formula it is always necessary to first compute the molecular percentage composition from the actual percentage composition as obtained directly by analysis. As an illustration, the analysis of bottle No. 1, Table III, gave the following:
 SiO_2 —69.91%; Al_2O_3 —0.91%; CaO —7.04%; MgO —1.56% and Na_2O —20.68%.
 These percentages are divided by the molecular weights.

69.91	60.3	= 1.1590
0.91	102	= 0.0090
7.04	56	= 0.1257
1.56	40.32	= 0.0387
20.68	62	= 0.3336
Total		1.6660

$$\frac{1.159 \times 100}{1.666} = 69.57 \text{ mol. per cent } \text{SiO}_2$$

$$\frac{0.009 \times 100}{1.666} = .54 \text{ mol. per cent } \text{Al}_2\text{O}_3$$

$$\frac{0.1257 \times 100}{1.666} = 7.55 \text{ mol. per cent } \text{CaO}$$

$$\frac{0.0387 \times 100}{1.666} = 2.34 \text{ mol. per cent } \text{MgO}$$

$$\frac{0.0387 \times 100}{1.666} = 20.00 \text{ mol. per cent } \text{Na}_2\text{O}$$

a value of -5.21 . This particular formula is applicable only in case $c + d$ is greater than $3b$, which is usually the case in commercial glassware

The second formula, $\frac{d}{b + c}$, which represents

Mol. percentage of Na_2O

Mol. percentage of CaO and $\text{MgO} + \text{mol. percentage of } \text{Al}_2\text{O}_3$

is not based on any theory. It is interesting to note that here also are certain exceptions and that these correspond to the same exceptions as cal

TABLE III

		Cc. of .01 N NaOH per 100 cc. solution.	RO_2	R_2O_3	RO	R_2O	$\frac{c - d}{c + d}(c + d - 3b)$	$\frac{d}{b + c}$
		Bottle no.	Solubility no.	(a)	(b)	(c)	(d)	
Group I	{	1	12.02	69.57	0.54	9.89	20.00	— 9.56
		2	8.71	72.18	0.92	7.97	18.95	— 9.88
		3	8.44	71.82	0.56	9.55	18.12	— 8.05
		4	8.40	73.45	0.60	7.85	18.10	— 9.54
		5	8.36	74.40	0.31	7.80	17.50	— 9.34
		6	8.35	74.44	0.26	7.30	18.03	—10.39
		7	8.12	69.97	0.94	8.64	20.45	—10.64
		8	7.20	73.92	0.39	8.40	17.29	— 8.47
		9	7.14	69.16	1.04	9.63	20.15	— 9.42
		10	6.81	72.90	0.46	8.70	17.94	— 8.42
Group II	{	11	6.33	77.67	0.75	7.88	13.70	— 5.21
		12	5.67	70.87	1.10	10.52	15.51	— 4.33
		13	5.50	71.43	0.96	9.00	18.57	— 8.57
		14	5.20	75.06	0.23	8.11	16.56	— 8.22
		15	4.90	73.52	1.09	8.95	16.44	— 6.48
		16	4.10	72.92	0.78	9.54	16.71	— 6.53
		17	4.10	75.94	0.48	8.52	15.04	— 6.12
		18	3.50	73.00	0.97	9.25	16.78	— 6.58
		19	3.50	75.69	0.62	8.33	15.37	— 6.07
		20	3.20	72.35	0.60	9.67	17.37	— 7.19
		21	3.20	71.52	1.00	8.86	18.61	— 8.67
Group III	{	22	2.86	69.46	0.67	12.38	17.49	— 4.77
		23	2.85	72.29	0.60	10.12	16.99	— 6.41
		24	2.27	74.10	0.51	10.31	15.08	— 4.48
		25	1.98	71.90	0.73	11.27	16.10	— 4.44
		26	1.96	75.12	0.64	8.96	15.28	— 5.82
		27	1.91	73.25	0.30	10.40	16.05	— 5.38
		28	1.51	73.37	1.47	9.39	15.77	— 5.27
		29	1.41	69.11	0.84	12.49	17.55	— 4.63

culated from Zulkowski's formula. Here also Nos. 6, 7, 13, 14 and 21 are out of order as related to their resistance numbers. It seems likely that factors other than composition influence the rate of disintegration, although

to a less extent. Such a factor might be surface condition, a smooth surface being more resistant than a rougher one in the case, for example, of two bottles of the same composition.

From a consideration of Table III the following is evident: All members of Group I have distinctly higher reactivity coefficients and solubility numbers than any other members of Group III. With three exceptions (Nos. 13, 14 and 21) the same holds in comparing members of Group I with the medium class, II. All glasses which have a solubility number greater than 6.5 have a reactivity coefficient greater than 8 and, with the three exceptions mentioned, all glasses having a solubility number less than 6.5 have a reactivity coefficient of less than 8. Glass having a solubility number not greater than 3 is of excellent quality as regards its resistant properties. This type of glass usually has a reactivity coefficient of less than 6.5. The ratio of the molecular percentage of R_2O to the combined mol. percentage of RO and R_2O_3 as computed, tends to show that the most resistant glass in the table gives for such values less than 1.5 and for glass in Group I, which is least resistant, values greater than 1.8. In Group II, or the medium class, with three exceptions, the values obtained by this second formula are between 1.6 and 1.7.

The value of using this second formula might be questioned. The lime to soda molecular ratio has been mentioned by various authors. It is usually considered that alumina adds to durability to a greater extent than lime and is often referred to as "glorified lime." The author has introduced this formula simply because of the fact that it is noticed that the magnitude of the values obtained by it is generally, though not always, of the same order as that of the numerical values as obtained by the reactivity coefficient.

The interior surface areas of four of these bottles were measured. This number included those which differed most in size and shape and were the most extreme cases of dissimilarity among the whole number (about 200) that were tested. If the resistance of the bottles had been calculated in terms of unit area instead of concentration per unit volume, the same comparable results would have been obtained throughout. Following are the inside area measurements of the four bottles, their volumes and alkalinity values expressed both in terms of concentration per unit volume and dissolved from 100 cm.² of surface.

Bottle no.	Area, cm. ²	Volume, cc.	Cc. of 0.01 N alk. per 100 cc. sol.	Cc. of 0.01 N alk. dissolved from 100 cm. ²
58	274.94	344	4.62	5.81
39	308.83	360	5.22	6.10
173	628.18	806	7.25	9.30
167	570.7	800	4.55	6.37

The numbers of the fourth column bear to one another nearly the same ratio as do the numbers of the fifth. There was seldom a case among a

large number tested where the differences of such ratios equalled ten per cent. The greatest discrepancies are apt to occur among smaller bottles but these may be tested in large beakers as in the case of tumblers. The above figures indicate that bottles may be tested on a basis of capacity and that such a basis should put them in their proper class whether of high, low or medium resistance.

Summary

The resistance to water of various types of soda-lime glasses has been studied.

A method of measuring this rate is suggested, which is simple and accurate and applicable to glass surfaces.

The relation of composition to resistance to water of various American bottles has been studied. It was found that these bottles varied considerably in resistance to water.

Two unrelated formulas applied to analytical data are in general agreement and indicate the importance of composition as a factor in the making of the most durable glass. Glass which gives a solubility number less than 5.5 after a six-hour test has sufficient resistant qualities for most purposes.

It has been found that with respect to composition, the actual analysis having been computed to molecular percentage composition, the "reactivity coefficient," as calculated, should be less than 8 for fairly resistant glass. If this reactivity coefficient is less than 6, the glass is of excellent quality and very resistant. It is to be understood that this is generally but not invariably the case, as factors other than composition are also involved, although to a less extent, in making glass of a resistant quality.

THE ACTION OF SLAG UPON SILICA, MAGNESITE, CHROME, DIASPORE AND FIRE-CLAY REFRACTORIES

BY R. M. HOWE, S. M. PHELPS AND R. F. FERGUSON¹

ABSTRACT

The resistance of magnesite, chrome, silica, diaspore and fire-clay brick to the action of five slags was studied by a new method. The brick and slag were reduced to a powder, mixed in several proportions, and the fusion points of the mixtures determined. The actual melting points of the mixtures, the porosity of the brick, and the depression of the fusion point of the refractory due to slag action are taken into consideration in interpreting the results. Magnesite had a slightly higher resistance to the action of most slags than did chrome. The behavior of silica brick varied considerably with different slags. The behavior of different types of fire-clay brick showed considerable variation, depending upon the nature of the slag, the composition of the brick, and its density.

In a previous paper² it was demonstrated that the action of slag on refractories is the resultant of two tendencies—penetration and solution. Experimental data were also presented to show “that a slag penetration test is of slight practical value, for its results may be obscured by a high or low resistance to solvent action.” Other plant and laboratory data led to the statement that “a test designed to show resistance to chemical action should give information of practical value.” Since the presentation of that paper it has been possible to make a number of tests by means of this latter method.

This test is based upon the principle that slags react with refractories forming mixtures or compounds with lower fusion points. The depression of the fusion point of the refractory due to this action is regarded as a measure of the intensity of the action. The actual fusion point gives an idea of the limit of safety when the refractory brick are in contact with molten slag.

Magnesite, chrome, silica, diaspore, and five kinds of first-quality fire-clay brick were compared. They were each exposed to the action of basic open hearth, acid open hearth, heating furnace, blast furnace, and coal ash slags.

Method of Procedure

Ten pounds of each sample of refractory brick was first reduced to the same state of subdivision. This precaution was taken in order to overcome any possible difference in resistance to slag that might arise from a variation in the fineness of the materials. A typical screen analysis of the prepared samples is given on following page.

¹ Industrial Fellows of the Mellon Institute of Industrial Research, University of Pittsburgh, Pittsburgh, Pa.

² “A Study of the Slag Test,” *Jour. Amer. Ceram. Soc.*, 6 [2], 466–473 (1923).

80 to 100 mesh.....	38.0%
100 to 120 mesh.....	13.5%
120 to 140 mesh.....	4.5%
140 to 160 mesh.....	4.5%
160 to 180 mesh.....	8.0%
Through 180 mesh.....	31.5%
	<hr/>
	100.0%

Batches were then made that contained 4, 8, 12, 16, 20, 30, 40 and 50 per cent of several kinds of slag mixed with the refractory materials. These batches were made into test cones. The fusion point of each cone was then determined and the results were recorded.

It was found necessary, in making these determinations, to set the clay, silica, and standard Orton cones in fire-clay pats. The magnesite cones were set in magnesite pats and the chrome cones in chrome pats. In the latter cases the round cone pat was divided into two sections, one for the Orton cones and the other for the test cones. This necessity arose from the fact that the magnesite, chrome, slag mixtures reacted with the fire-clay base and gave results from 2 to 16 cones too low. Each fusion point determination was extended over a period of four hours, this slow schedule having been adopted to allow the more complete action of the slag.

Experimental Data

The chemical composition and fusion point of each refractory brick is given in Table I. The analysis and fusion point of each slag is given in Table II. The fusion point of each mixture is given in Tables III, IV, V, VI, and VII. An "x" in the fusion point tables indicates that this material or mixture fused above cone 36, the limit of the gas furnace in which these determinations were made.

TABLE I
ANALYSES AND FUSION POINTS OF REFRACTORY MATERIALS

Nature of brick laboratory letter	Diaspore		Fire clay		D	C	Silica		Chrome
	B	E	A	E			L	H	I
Silica	30.98	47.94	50.98	57.12	62.20	80.06	96.58	7.80	12.94
Alumina	63.20	47.13	43.94	38.01	33.44	18.30	.74	2.42	23.17
Ferric Oxide	2.62	1.20	3.16	1.94	1.79	.88	.50	3.62	13.45
Titania	3.32	2.15	...	1.97	1.79	1.34	...	.00	.00
Lime	.21	.73	.36	.44	.38	.20	1.88	3.86	.07
Magnesia	trace	.11	.52	.50	.25	.07	.16	82.40	8.95
Alkalies	.46	1.23	1.32	.16	.50	trace	.21	trace	.03
Chromic Oxide	...	...	...	...	...	...	...	...	41.24
Total	100.79	100.49	100.28	100.14	100.35	100.85	100.07	100.10	99.85
Fusion Point in									
Cones	36	33½	32½	32½	30½	28	31½	...	...

TABLE II
ANALYSES OF SLAGS USED IN TESTS

Slag	Basic open hearth	Blast furnace	Heating furnace	Acid open hearth	Coal ash
Silica	23.32	36.82	16.98	50.16	56.76
Alumina	0.30	11.70	3.91	3.00	28.59
Iron Oxide	26.60	3.40	75.30	30.25	9.25
Titania	1.02	0.54	0.70	1.54	1.40
Lime	37.95	43.40	0.79	2.32	1.57
Magnesia	6.96	2.47	0.14	0.93	0.45
Manganese Dioxide	4.24	0.89	1.89	11.72	trace
Alkalies	0.09	0.57	0.06	trace	1.34
Total	100.48	99.79	99.77	99.92	99.36
Fusion Point	Cone 7	Cone 3	Cone 2	Cone 12	Cone 8

TABLE III

FUSION POINTS OF ACID OPEN HEARTH SLAG—REFRACTORY BRICK MIXES*

Brick designation	Per cent slag in mixture								
	0	4	8	12	16	20	30	40	50
Diaspore B	36	35	33.5	33	33	30.5	26	20	13
Fire Clay K	33.5	33	31.5	30	29	27	16	14	9
Fire Clay A	32.5	32.5	32	30.5	28	26	13	11	8
Fire Clay E	32.5	32	29	26	20	16	14	11	9
Fire Clay D	30.5	29.5	20	17	15	13	10	8	6
Fire Clay C	28	27	20	18	17	16	13	8	6
Silica L	31.5	31.5	31.5	31	31	29	28.5	28	28
Magnesite H	..	..	..	..	36	33	32	31	27
Chrome I	..	36	33.5	31.5	30	20-26	15	13	12

* The diaspore and fire-clay brick are arranged in order of increasing silica content.

TABLE IV

FUSION POINTS OF BLAST FURNACE SLAG—REFRACTORY BRICK MIXES*

Brick designation	Per cent slag in mixture								
	0	4	8	12	16	20	30	40	50
Diaspore B	36	33.5	32.5	29	20	14.5	14	14	10
Fire Clay K	33.5	32.5	31	26	18	14	13.5	13.5	12
Fire Clay A	32.5	30	29	20	17	13.5	13	12.5	9
Fire Clay E	32.5	29	29	17.5	13.5	13	13	12.5	11
Fire Clay D	30.5	26	20	13.5	11.5	11	9	7	5
Fire Clay C	28	20	14	13	10	8	5	2	2
Silica L	31.5	31	31	30.5	30	27	17	6	3
Magnesite H	..	..	..	..	36	33.5	26	17	14
Chrome I	..	..	..	35	34	32	16	9	8

* The diaspore and fire-clay brick are arranged in order of increasing silica content.

TABLE V
FUSION POINTS OF BASIC OPEN HEARTH SLAG—REFRACTORY BRICK MIXES*

Brick designation	Per cent slag in mixture								
	0	4	8	12	16	20	30	40	50
Diaspore B	36	33.5	32.5	20-26	14	12	11	10.5	10
Fire Clay K	33.5	32	30.5	18.5	14.5	14	12	8	6
Fire Clay A	32.5	30.5	26	16	15	13	9	8	5
Fire Clay E	32.5	30.5	26	13	11.5	10.5	7	6	2
Fire Clay D	30.5	28	17	11.5	11.5	10	9	2.5	2
Fire Clay C	28	20	14.5	12	11	8	3	2	1
Silica L	31.5	31.5	31.5	31	31	30	19.5	16	4
Magnesite H	..	..	..	..	..	..	..	..	..
Chrome I	..	..	..	..	..	..	..	..	..

* The diaspore and fire-clay brick are arranged in order of increasing silica content.

TABLE VI
FUSION POINTS OF HEATING FURNACE SLAG (FUSION POINT = CONE 2)—REFRACTORY BRICK MIXES*

Brick designation	Per cent slag in mixture								
	0	4	8	12	16	20	30	40	50
Diaspore B	36	34	32.5	31.5	29.5	20	15	11	9
Fire Clay K	33.5	32.5	31.5	30	28	19	14	10	9
Fire Clay A	32.5	31+	30	26	19	18	10	9	8
Fire Clay E	32.5	31+	29	26	18	16	11	8	8
Fire Clay D	30.5	28	18	13	11	10	9	8	8
Fire Clay C	28	20-26	17	15	14	13	12	11	10
Silica L	31.5	30.5	29.5	28.5	28.5	28.5	28	27	26
Magnesite H	..	..	..	..	..	..	..	..	..
Chrome I	..	..	..	..	..	36	35	36	36

* The diaspore and fire-clay brick are arranged in order of increasing silica content.

TABLE VII
FUSION POINTS OF COAL ASH SLAG—REFRACTORY BRICK MIXES*

Brick designation	Per cent slag in mixture								
	0	4	8	12	16	20	30	40	50
Diaspore B	36	35.5	35	34.5	34	33.5	33	32.53	30.5
Fire Clay K	33.5	33+	33	33	32.5	32.5	32	30.51	30
Fire Clay A	32.5	32	32	31.5	31.5	31.0	30.5	29	20-20
Fire Clay E	32.5	32	31.5	31.5	31.5	31.0	31	28	26
Fire Clay D	30.5	30.5	30	28	27.5	27	26.5	19	15
Fire Clay C	28	28—	27.5	27.5	27	26.5	20-26	18.5	16

* The diaspore and fire-clay brick are arranged in order of increasing silica content.

Discussion of Results

The data obtained were plotted in several ways in order to simplify their study, but the arrangement shown in Figures 1-4 proved to be the most effective. In plotting these curves the silica contents of the diaspore, fire clay, and silica brick were taken as the abscissae. The fusion points

of each brick, with or without slag, were taken as the ordinates. The points representing equal slag concentrations were then connected.

When the resulting curves are examined, it is evident that a given slag does not exert the same influence upon every brick. Eight per cent of basic open-hearth slag, for example, lowers the fusion point of fire brick K 3 cones, of fire brick D $13\frac{1}{2}$ cones, and of silica brick I, only $1\frac{1}{2}$ cone. Increasing amounts of a given slag also exert a greater influence, as is shown in the action of basic open-hearth slag upon fire brick C. Four per cent of this slag lowers the refractoriness of the brick 8 cones, 8 per cent $13\frac{1}{2}$ cones, 12 per cent 16 cones, 20 per cent 20 cones, and 50 per cent 27 cones. It is to be noted also that different slags do not exert the same

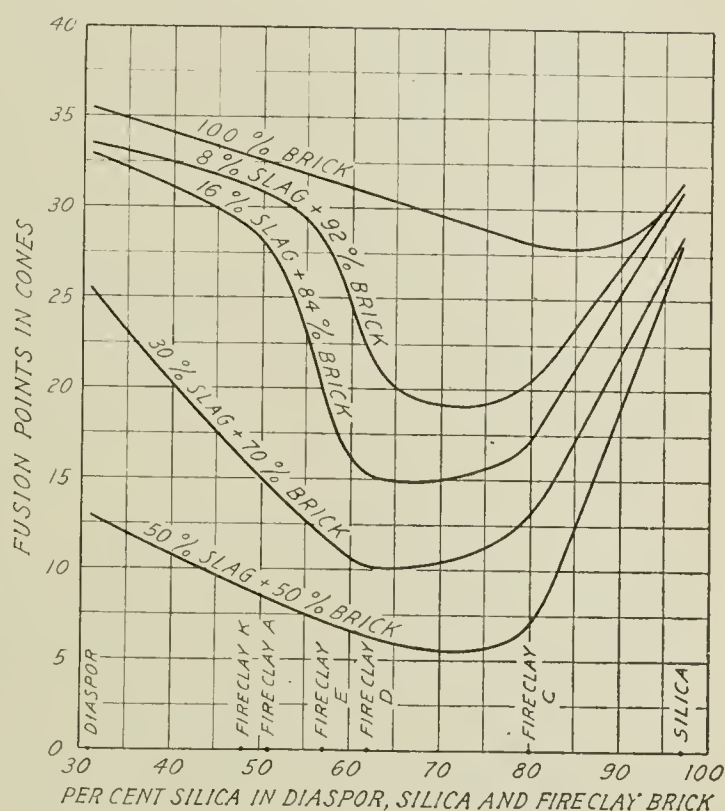


FIG. 1.—Fusion points of diaspore, silica and fire-clay brick mixed with acid open-hearth slag.

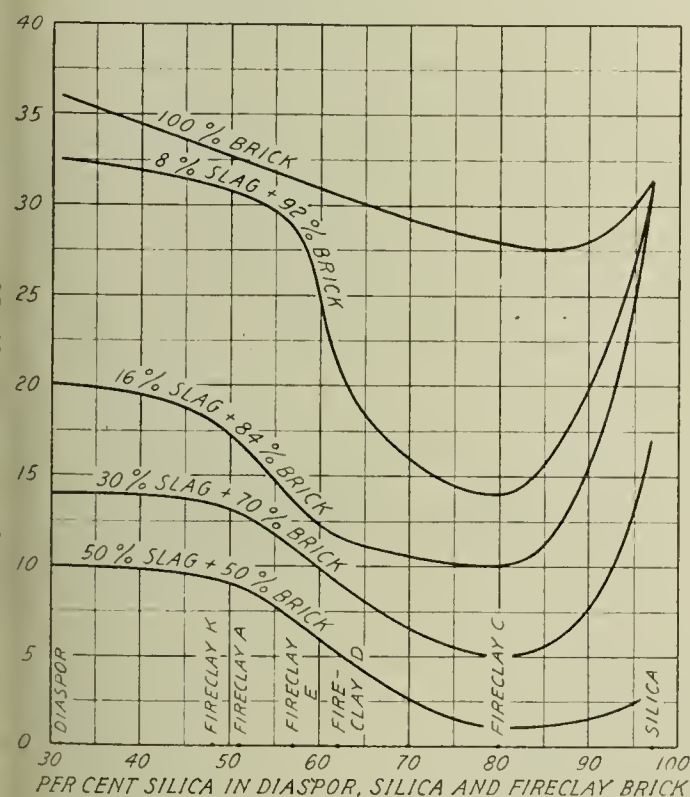


FIG. 2.—Fusion points of diaspore, silica, and fire-clay brick mixed with blast furnace slag.

These facts show that it is possible to distinguish between the action of different slags upon refractories by laboratory methods. They also show that the brick which are least affected in this test show a high

influence upon any given brick. The fusion point of brick K is decreased $16\frac{1}{2}$ cones by the action of 30 per cent of acid open-hearth slag, and from $1\frac{1}{2}$ to $21\frac{1}{2}$ cones by equal amounts of the other slags.

Thus the behavior of the slags in the test agrees with that which has been observed in service in three general but important details.

1. The intensity of the action increases with the slag concentration.

2. Different slags do not exert the same influence upon any one material.

3. The influence of a given slag varies with different refractory materials.

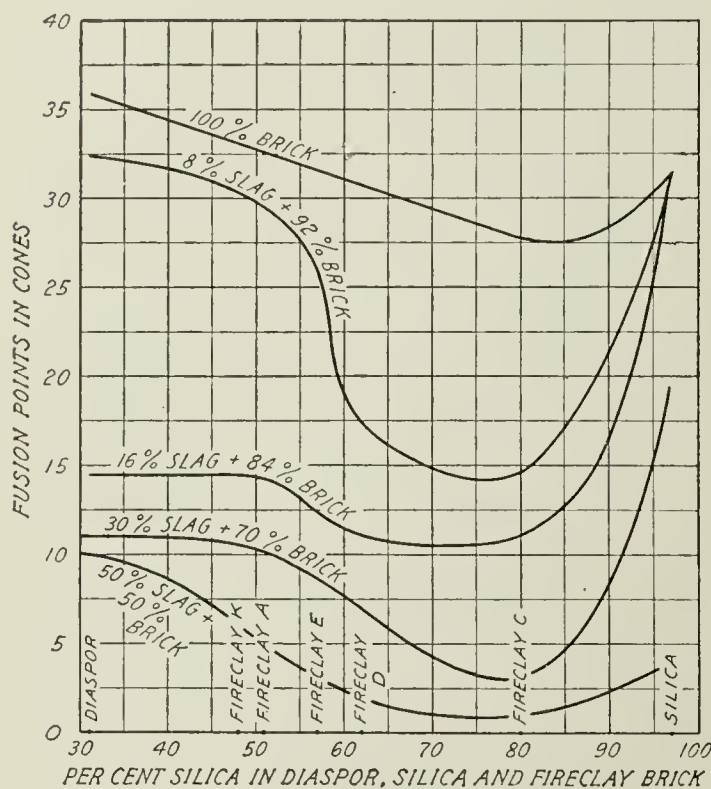


FIG. 3.—Fusion points of diaspor, silica, and fire-clay brick mixed with basic open hearth slag.

better service. This is due to the fact that the slag action is restricted to a smaller area in the case of the denser brick.

The test described does not take this fact into consideration, for the influence of density and of the texture of the particles is destroyed in the preparation of the sample. It is believed, however, that allowance can, to a certain extent, be made for this condition by taking into consideration the probable slag absorption of different brick.

Silica brick will not absorb more than about 20 per cent of this same slag. Consequently, they should always offer a higher resistance to the action of this slag than fire-clay

resistance to the slags to which they are exposed in service. Consequently, the use of this method as a means of studying slag action is justified. At the same time there are conditions where this test, like most others, may lead to erroneous conclusions if the results are improperly interpreted.

Slag action has been subdivided into two steps: penetration and solution.¹ Of these, solution is often the more important, for the penetration of several brick may be the same. At the same time, conditions exist where two brick differ more in resistance to penetration than in resistance to solution, and in those cases the denser brick may give the

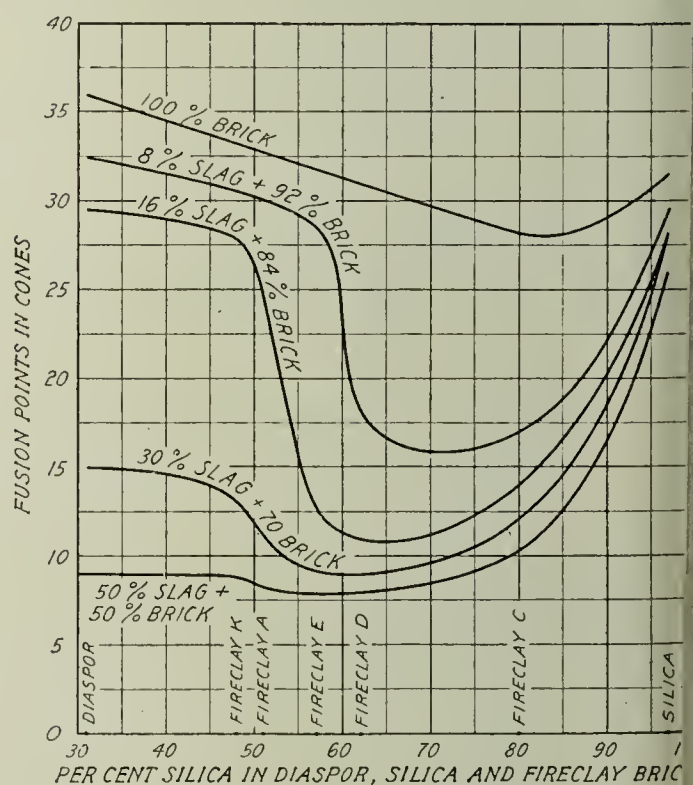


FIG. 4.—Fusion points of diaspor, silica, and fire-clay brick mixed with heating furnace slag.

¹ Penetration refers to the physical process by which a liquid enters the pores of a solid material. The word solution is used in a broad sense and includes the dissolving of solids, liquids, and gases by solid or liquid materials. In this broad sense the term solution applies to the action between lime and silica brick in a lime kiln, as well as to the action of a slag upon the exposed end of a fire brick.

brick C. This conclusion is based upon the fact that a mixture containing 10 per cent of this slag and 80 per cent of silica brick is more refractory than fire-clay brick C, although it is free from slag. Silica brick also possess an advantage over fire-clay brick A and E with this particular slag, although this advantage might be overcome by making the latter sufficiently dense to prevent appreciable slag absorption.

Fire-clay brick K possess an advantage over fire-clay brick A and E, but this might be lost due to slight differences in density.

The writers believe that reasoning of this kind must be applied in the interpretation of these slag test results. While burn is an important factor, there is no reason to believe that its influence will be altered under the conditions of the test.

Other outstanding features of the results are as follows:

1. Magnesite and chrome brick showed a particularly high resistance to the action of basic open-hearth slag, as they do in actual service.
2. Brick made from diaspore were but slightly affected by the action of these slags. They are often used where slag action is unusually severe.
3. Silica brick showed a high resistance to the action of acid open-hearth and heating furnace slags, both of which are composed almost entirely of silica and iron oxide. They showed a low resistance to the action of basic open-hearth and blast furnace slags, two slags that are high in lime.
4. The behavior of the fire-clay brick differed considerably as it does in service. With the particular slags used in the investigation, high alumina appeared to be an advantage. The advantage was not the same, however, in all cases. Other slags may be expected to favor brick high in silica, as has been demonstrated in service. Certain coal ashes, for example, are said to attack brick high in alumina more readily than those which are high in silica. The same is true of slags encountered in the metallurgical industries.

In conclusion, the writers wish to acknowledge the valuable assistance of W. R. Kerr, W. M. Walker, and Foster Robertson in making the various determinations.

METALLURGICAL REQUIREMENTS OF REFRACTORIES FOR FURNACES MELTING COPPER ALLOYS

BY H. W. GILLET

ABSTRACT

The requirements for refractories for pit furnaces are less severe than for those for open-flame or electric furnaces. Suitable refractories for electric furnaces will meet the needs of the other types as well. Attention is therefore directed to the development of better refractories for electric furnaces melting non-ferrous alloys. The most important types of electric brass furnaces are described in relation to their refractory problems. The requirements vary with the type of furnace. All types require refractories that will resist penetration by metal, will not spall or crack, have low thermal conductivity and high mechanical strength at working temperatures.

A refractory combining these properties in sufficient degree would be welcome by users of copper-alloy furnaces, especially electric furnaces, and a rather high price would not be an insurmountable barrier to its use if it will markedly increase the lining life.

Commercial copper alloys contain from 50% copper up, the common alloying elements being zinc, tin and lead. Nickel, aluminum or iron enter such alloys more rarely. Since yellow brass and the red brasses are the most common alloys, the furnaces for melting these alloys are typical of those used for all the copper alloys.

These alloys are all poured at from 1000° to 1300°C. Hence as far as mere temperature goes the requirements are not severe.

The alloys are melted in a variety of furnaces. When crucible furnaces are used, the refractories do not come in contact with the metal.

In a natural draft coal- or coke-fired furnace, the refractories must not flux readily with the fuel ash, and should be strong enough to stand barrages off clinkers without cracking away. Few brass furnaces of any type are run 24 hours a day so the refractories must not spall badly on heating and cooling.

Moderate thermal resistivity is desirable, but the heat losses in the flue gases of a coke furnace are so great anyhow that production is not greatly speeded up by the small saving of heat obtained by better thermal insulation.

These pit fires were used in the earliest history of the brass industry and did not change much for a hundred years.

When more rapid production was desired, forced draft began to be used, giving higher furnace temperatures and slightly more severe conditions to be met by the refractories. Forced draft furnaces are, however, not very common. The furnaces using solid fuels are generally lined with fairly refractory fire brick about 4½" thick. Circle brick is generally used, though square furnaces using standard brick are common. These furnaces in the usual sizes, generally produce 100,000 to 400,000 lbs. of metal before relining is done.

The furnaces are relined when the lining has worn down so thin that the fuel space is too great and fuel is therefore wasted. The life can be greatly prolonged by thorough patching at least once a week. Several refractory mixtures that can be applied hot are on the market.

Crucible furnaces fired by oil, less commonly gas, do not have to contend with clinkers or with fluxing with ash, and are still usable even after the lining has worn away considerably. Hence these show, on the average, a higher production between relinings, 200,000 to 800,000 lbs. being common.

On the other hand, in a poorly designed oil or gas furnace with the burner so placed that the flame impinges directly on the lining, the life may be low. By placing the burner in a side chamber or having the burner enter at an angle so that the flame swirls about the crucible, better lives are obtained.

Circle fire brick are the common linings for these furnaces, although rammed up carborundum linings are used to some extent. They give a longer life, but reduce the thermal efficiency somewhat. Patching with carborundum and washing the surface with carborundum cement is often advised.

Furnaces from which the crucible is lifted to pour seldom take over 100 lbs. per charge and 200 to 300 lbs. is the normal size. Tilting crucible furnaces, from which the metal is poured into a ladle, run up to 400 lbs. or more in normal sizes, but in any crucible furnace the fragility of the crucible keeps the capacity per heat down.

For furnaces of larger capacity we have to go to the hearth-type furnace. Now and then one finds a coal- or oil-fired tapping reverberatory, but these are very rare, coal-fired furnaces being still more rare than oil-fired. Tilting, open-flame oil furnaces are the chief fuel-fired hearth-type furnace. A few open-flame furnaces fired with natural gas are used in favored localities.

In the hearth-type furnaces the hearth has to be metal-tight and instead of the separate, easily replaceable cover of the crucible furnaces, the domed roof of the open-flame furnace is an integral part of the lining. Since the heat is more directly applied to the charge, the refractories of the open-flame are not heated quite as hot as those of the crucible furnaces where the heat must be driven through the walls of the crucible. The better application of heat in the open flame furnace makes it possible to get rapid production and slight variations in thermal efficiency are of more practical importance than in the crucible type, so the lining of the open-flame furnace is generally thicker than in the crucible types.

In a crucible the metal, with its usual charcoal covering, is pretty well protected from the gases of combustion, nor do these gases sweep over a large area of metal. But in the open-flame furnace, with its wide, shallow bath, on which it is difficult to maintain a charcoal covering, the gases

have ready access to the metal. This means that oxidation must be guarded against and that the volatile metal, zinc, is readily swept out by the gases. The first point makes it difficult, though not at all impossible, to produce alloys of the highest quality in open-flame furnaces, but the second makes it entirely impractical to melt alloys high in zinc in such furnaces.

There are several forms of open-flame furnace. One is of approximately spherical shape, built up of special shapes of fire brick. Another is rectangular, of standard brick with suitable arched roof. Still others are horizontal cylinders or ovoids, and may be lined with circle brick or with rammed-up linings. Carborundum fire sand is widely used in the rammed-up linings, but it is quite a trick to ram up such a lining and have the roof portion stay in place.

The necessity for metal-tightness in the hearth requires that brick shall not be too porous, shall have true faces so that they can be laid closely without too much cement, and shall not crack or spall readily to form pockets into which metal can run, contaminating the next heat if of a different composition, or damaging the lining if allowed to freeze. A rammed-in layer of carborundum fire sand and fire clay, fire clay and ganister, or some other plastic mixture is usually put over the bricks in the hearth. If leaded alloys, even those not very high in lead, are melted, the lead is very likely to segregate to the bottom of the melt and seep into the hearth.

The hearth must have considerable strength because ingots or heavy pieces of scrap may be thrown in, or, in case of mechanical charging, dumped in. Where borings enter into the charge a layer of these charged first will protect the hearth a good deal.

In ordinary melting in open-flame furnaces no slag is carried, though when handling gates to which molding sand adheres, a lime slag, sometimes with a little fluorspar, may be used. To avoid this the gates are sometimes cleaned in a tumbler. Glass or borax may be used, but this is rarely done, so that in general the hearth has to withstand only the fluxing action of a little adhering sand. When phosphor bronze is melted small amounts of P_2O_5 may be produced which has a strong fluxing action.

The hearth must introduce no detrimental impurities into the charge. Conditions within the furnace are held as reducing as is compatible with fuel efficiency and there is a possibility of reduction of some metal such as silicon from the hearth. However, this is of real importance only when handling aluminum bronze, in which case the material of the hearth must be of materials not reduced by aluminum at the temperature used.

In the operation of an open-flame furnace the flame is usually held long enough so that it burns beyond the spout, so that the flame plays directly on the refractories about the spout. The spout needs frequent patching, but this is not difficult as the spout is accessible.

The body of the lining is none too accessible and open-flame furnaces therefore may not be given as thorough patching as they really need. The attention paid to patching and the quality of workmanship in putting in the lining have a great deal to do with its life.

Open-flame furnaces are very seldom used in capacities below 500 lbs. The average capacity is around 1000 lbs. while one ton furnaces are common and a few are in use up to 5 tons.

Open-flame furnace linings in general produce around 1,000,000 lbs. before complete relining is necessary and runs of 2,000,000 to 3,000,000 are not uncommon. On the other hand, some of the rammed-up linings may give only 100,000.

The desirability of more perfect control of temperature, avoidance of oxidizing conditions, of fuel storage, the necessity for more rapid and cheaper production of alloys high in zinc, *i. e.*, of furnaces of larger capacity than the crucible type of fuel-fired furnaces required by those alloys, the desirability of making the work of the furnace tenders less hot and arduous, and the need for furnaces involving lower losses of metal in melting, all tended to bring about the introduction of the electric furnace for melting brass and other copper alloys.

The first electric brass furnace in commercial operation started up seven years ago and there are now well over 400 in use. The American Brass Co. has over 80 electric brass furnaces and the brass rolling mill industry as a whole does the great majority of its melting electrically. The foundries as well as the rolling mills have taken up electric melting, the Ford Motor Car Co., for example, using 8 one-ton furnaces.

Electric brass furnaces will ultimately melt not far from 90% of the country's output. Hence the problem of refractories for electric brass furnaces is rapidly becoming even more important than that of refractories for fuel-fired brass furnaces.

Electric furnaces used for copper alloys are very different from the direct arc electric furnaces used for steel melting. Disregarding a few types which have only slight use, there are three general types of electric furnace widely used on brass, each of which has its own special refractory. These are the Baily, a reflected-heat type used mainly by foundries, very little by rolling mills, the rocking indirect arc type, used by both foundries and rolling mills, and the Ajax induction furnace, used chiefly by rolling mills.

There are some points on which all three types have similar problems. All are hearth type furnaces and the general requirements stated for refractories for open-flame furnaces apply. Thermal efficiency is of great importance on account of the cost of electric heat, so the electric furnace linings must be designed to minimize heat loss. The electrical conductivity of the refractories at operating temperatures has to be taken into account.

Brief descriptions of the three main types will have to be given in order to make intelligible the special requirements they impose on their refractories.

The Baily furnace (see Figs. 1 and 2) is heated by a granular carbon resistor held in a trough made of carborundum.

That the carborundum of the trough is a fair electrical conductor is an advantage, because the trough carries part of the current and produces part of the heat, thus reducing the required current density in the granular carbon resistor and giving more even heating. The trough is supported on piers, the part of the pier directly supporting the trough usually being silica brick, and is situated above the charge and placed away from the walls so as to allow free radiation. The piers must not be too good electrical conductors, else the current would tend to short-circuit down to and

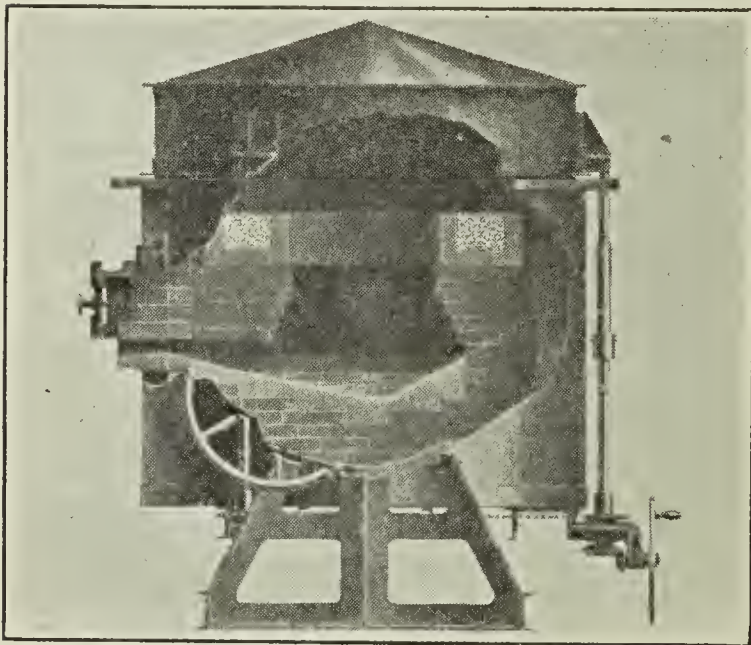


FIG. 1.—Cross-section of a Baily electric furnace showing trough forming the resistor element, hearth, and pouring spout.

through the metal bath. The lining is of high grade fire brick, usually a highly aluminous brick such as Corundite, backed up by Silocel powder. The hearth is tamped up of carborundum fire-sand, fire clay and water-glass, and is sometimes placed in an iron pan to check penetration of the metal.

In the early days the trough was rammed up about a wooden form and baked in place. It was soon found necessary to build the trough of sections made like a regular carborundum brick. The trough is still the weakest point of the refractories of this furnace. In order to heat the charge at a rapid enough rate to get any production, the interior of the granular resistor itself must run hot, probably at about 1800°C . A granular resistor is prone to develop hot spots, and the leeway between the operating temperature of the resistor and the point at which the trough will fail is not very great. The whole furnace design is built around the requirements of the trough. In order to provide free radiation from the trough there is a good deal of waste space in the furnace, making the furnace big for its capacity, and involving large wall losses and high heat storage.

The furnace, in a size rated to contain 1500 lbs. and usually run with perhaps 1200, is only operated at around 100 kw. or less, a very low rate of power input for a furnace of the size. A higher rate of power input would greatly increase the output and the efficiency and lower the melting

cost in this type of furnace. But attempting to raise the power input too soon breaks down the trough and puts the furnace out of commission. The furnace is often provided with a pyrometer in the roof which gives a check against overheating. The pyrometer does not tell anything as to the temperature of the charge, and it is not needed as far as the maintenance of the roof itself goes, but merely shows indirectly whether dangerous temperatures are being reached in the trough.

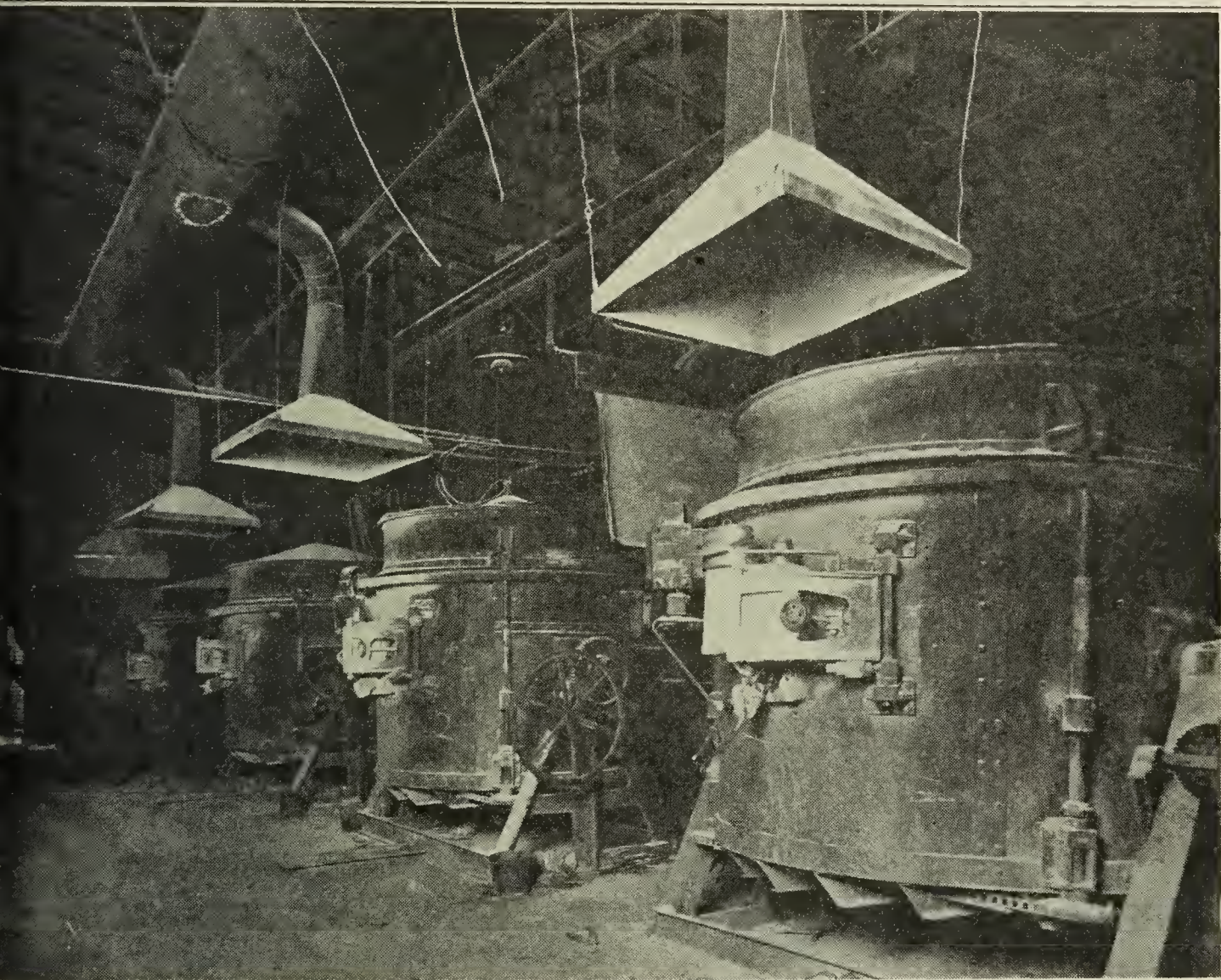


FIG. 2 —Baily electric brass furnaces.

In general the furnace produces somewhere around 250,000 to 1,000,000 lbs. before the trough needs replacement with, say 750,000, as the average. The piers and hearth are repaired or replaced at the same time. The brick linings should outlast several troughs.

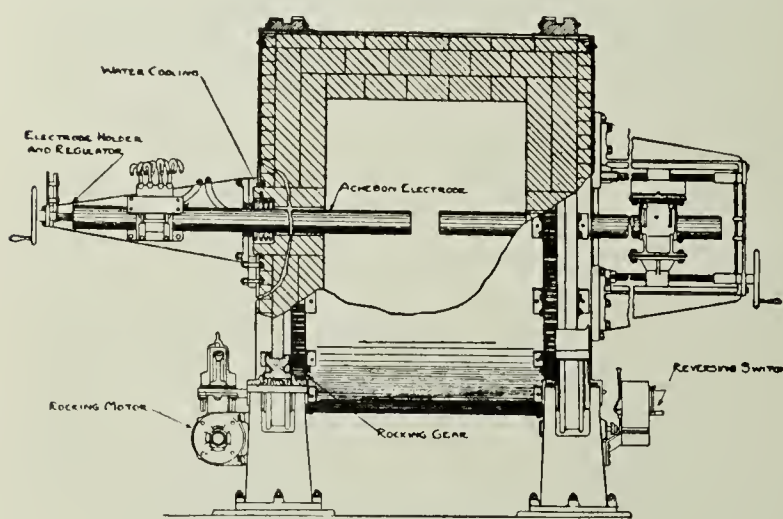
While the makers of this furnace express themselves as considering the refractories entirely satisfactory, it is obvious that a resistor trough more refractory than carborundum, and not readily oxidizable by air entering when the furnace is opened, would allow the use of a higher power input. This would increase the daily production, which in this furnace is relatively low, decrease interest charges and lower the melting cost.

Some other furnaces of the same general type, in that the heat is largely sent to the charge by reflection from the walls and roof, have been brought out, in which the trough is either entirely avoided or the design is so planned that some damage to the container or the resistor does not put the furnace out of business, but these types usually gain this advantage at the expense of some other advantage.

The next type, the moving indirect arc type, is not hampered by trough limitations and operates at a much higher rate of power input, the limit of the rate being safety to the lining. The 500 lb. size of this type takes 75 to 125 kw. and the one ton size 300 kw.

Half a dozen forms of the moving indirect arc furnace have been developed in this country and a couple of forms are being developed in Germany and one in England.

The rocking furnace made by the Detroit Electric Furnace Co., which is licensed to operate under the Bureau of Mines patents on this type of



Detroit Furnace—Sectional View

FIG. 3.

furnace, is the main form of this type. This is shown in Figs. 3 and 4. An arc plays between the electrodes, heating the charge and the furnace walls. When the metal is melted, the furnace rocks back and forth so that all the circumference of the lining save only that section occupied by charging door and pouring spout is washed by the metal. This takes up the heat stored in the

walls and brings them down to the temperature of the metal.

The end walls are not washed, but are somewhat shielded from the arc by the electrodes. The rocking also mixes the metal so that the surface does not become overheated, thus making it possible to operate on alloys high in zinc.

Since the whole furnace lining is the hearth at one time or another in the rocking cycle, metal-tightness of the lining is important. In melting a leaded bronze containing over 25% lead, over 100 lbs. of lead went into the hearth on the first heat in a one-ton furnace, and 50 lbs. on the second heat, while the third and later heats showed no further loss into the hearth.

Since most electric brass furnaces operating on alloys high in zinc work under slight pressure, the zinc vapor present in the furnace atmosphere may go through a too porous brick or a crack, and condense in the colder portions of the lining.

The presence of lead or zinc from these causes, or of fines of the alloy being melted that have run through a crack, not only tends to disintegrate the lining by expansion as the frozen metal heats up when the furnace is heated up again, but also cuts down the heat insulating value of the lining.

The lining is regularly composed of three layers, the inner of highly aluminous fire brick such as Corundite or Suprafrax, backed up by a layer of some lighter brick, less refractory, but a better heat insulator, which in turn is backed up by Silocel brick. Sometimes only two layers, Corundite and Silocel, are used.

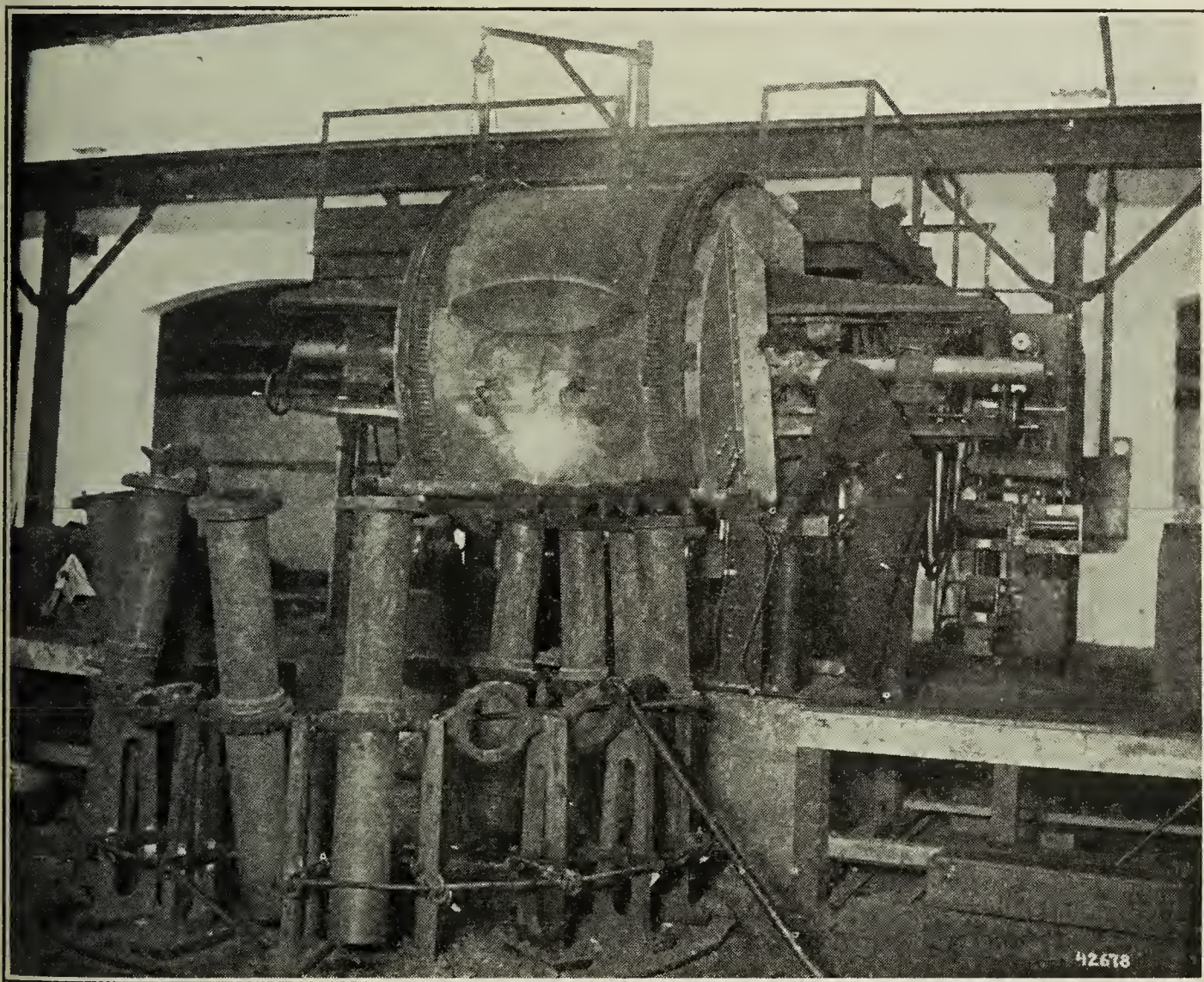


FIG. 4.—Detroit electric furnace pouring copper.

It is desirable to have good electrical insulation about the electrodes and that the hole through which they enter be smooth. Alundum cement is therefore used at these points.

The furnace rocks only slowly, making about two complete oscillations per minute, so that the eroding effect of the moving metal is not very great.

It is desirable from the operating standpoint to charge mechanically, rocking the furnace so that the charging door is up, and dumping the charge in through a funnel. The lining must stand this rather rough treatment.

The arc is supposed to be kept well centered in the furnace. Lining have been badly damaged by operation so careless as to bring the arc close to one end wall. The higher the refractoriness of the lining the less damage such carelessness can do.

The necessity for keeping the arc well centered so as not to overheat any part of the lining has made it desirable to use a single phase arc. From the electrical point of view the use of a three-phase arc would sometimes be advantageous and a couple of the moving indirect arc furnaces developed in this country, and those being developed in England and Germany use three-phase arcs. None of these have yet come into real commercial use, and the shorter life of the refractories in such a design is one of its worst drawbacks.

The one-ton Detroit furnaces usually produce between 750,000 and 1,500,000 lbs. of metal before the inner course of brick is replaced. The bricks directly over the charging door are less thoroughly keyed in place than the rest of the lining, and countersunk holes are usually drilled in these bricks and the brick held to the shell by bolts.

A very similar furnace, the Booth, has the charging door at one end of the furnace, the electrode support being attached to the door, and has the pouring spout also at the end. This furnace can be rotated completely, which involves the use of sliding contacts in the electric circuit. The furnace also has the further drawback of not being adapted to mechanical charging. As an offset to these drawbacks, it is somewhat easier to give stability to the lining of the Booth, as there is no opening on the circumference of the drum. Hence a one-piece refractory cylinder is used for the body and disks for the ends, making a three-piece lining. Suprafrax is commonly used for this. A layer of Silocel is placed between this lining and the furnace shell. The end of the furnace has to be taken off in order to reline the furnace. In a one-ton furnace it would be something of a job to insert a new inner one-piece lining satisfactorily without setting the furnace up on its end. The firing of a lining of that size also involves some problems for the refractory manufacturer. It is a question whether a one-piece lining, one made up of large blocks, or one made up of ordinary circle brick sufficiently true to shape to allow good brick-laying, will prove best in the long run.

The Booth rotating furnace is rarely used save in rather small sizes, 250 to 500 lbs. capacity. These give 150,000 and 300,000 lbs. as the average production between relinings.

Both Detroit and Booth furnaces are in use for melting cast iron, being especially useful where borings have to be melted. In such service a 250-lb. Booth produces around 60,000 lbs. between relinings, or less than half the average when operating on non-ferrous alloys.

The third important type of electric brass furnace is the vertical ring

induction furnace, shown in Figs. 5 and 6. In this furnace the heat is generated in the molten metal itself by virtue of its electrical resistance. Because the resistance is low, the current has to be very high and the cross section of the metal to be heated small. Hence the current is produced by induction and the resistor is a wide, but thin loop of molten metal so placed below the main body of the furnace that the tendency of a molten conductor to separate due to the so-called "pinch effect" is prevented by the hydraulic head of the metal above it. The furnace must have a complete loop of metal in the resistor to operate, so the furnace is not completely emptied, always operating with some molten metal in the bottom. A freeze-up ruins the lining, hence the furnace is run 24 hours a day, or, if not operated at night, is supplied with enough power to keep the metal left in molten.

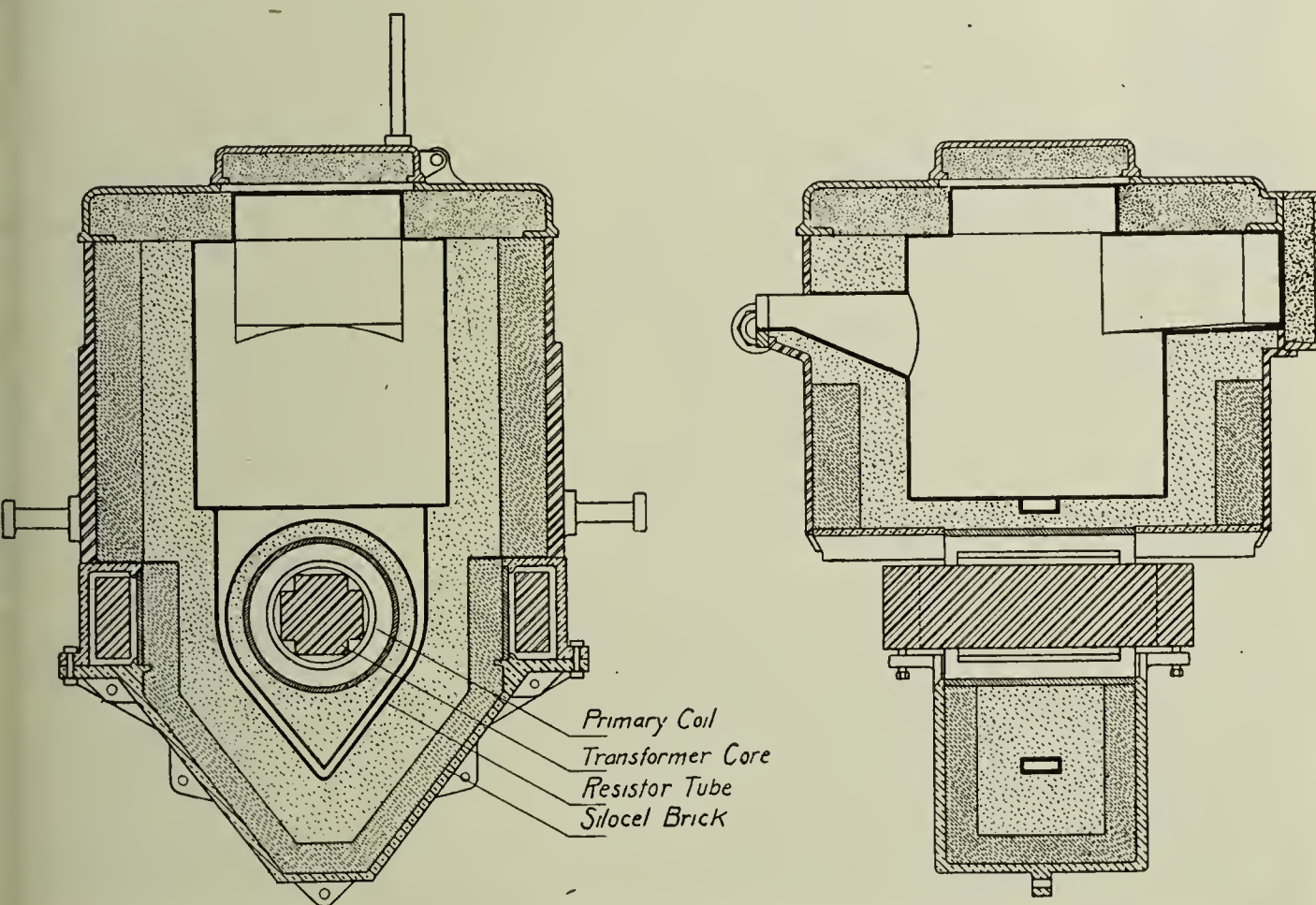


FIG. 5.—Diagram of Ajax-Wyatt electric brass furnace.

There is a constant flow of cooler metal into the resistor from above, and a constant forcing out of heated metal from the resistor into the hearth proper.

Since the heat is generated in the metal itself the refractories are not hotter than the metal. This type of furnace is extraordinarily compact and hence the wall losses are low. The furnace is inherently one of very great thermal efficiency.

The Ajax-Wyatt furnace is the only form of this type in real commercial use. This furnace is lined with a complete rammed-up lining of Johns Manville asbestos cement, No. 26 or No. 29, within a Silocel layer which

is next the shell. The lining is rammed up about a form, sometimes of wood which is removed, sometimes of brass which is left in and serves as the resistor when a newly lined furnace is being started up. In either case molten metal is poured in from another furnace when starting. Sometimes the lower half of the lining, about the resistor loop, is a molded refractory.

The lining inside the loop has to be thin on account of the small space allowed by the electrical requirements of this type. The primary coil and transformer leg within the loop are cooled by a current of air from a blower.

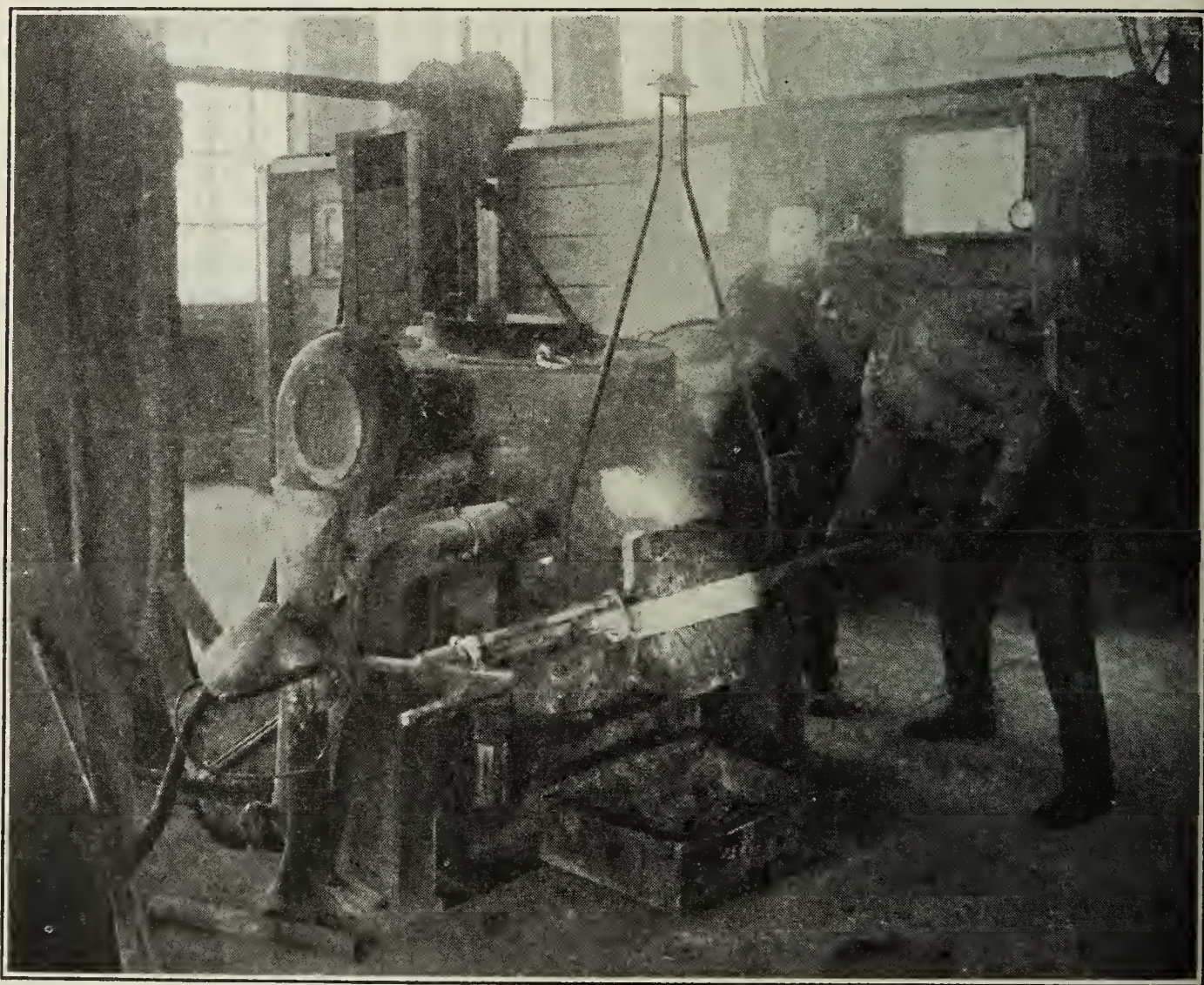


FIG. 6.—Ajax-Wyatt electric brass furnace.

In other types of electric furnace, penetration of the lining by metal is detrimental, but in this type it is fatal. If the metal works back to the shell so that the loop becomes short-circuited, further operation of the furnace is impossible. Hence it is essential that the lining be originally free from cracks or porosity, and remain so. Therefore the ramming must be most carefully done, and the lining must be very slowly and carefully dried out. Without the utmost care on this point, the lining may fail on the very first heat.

The choice of refractories is limited to those whose electrical conductivity is not too high, and whose heat conductivity is not too great, since the first would alter the electrical behavior and the second would endanger the primary and the transformer leg within the loop.

The slight flexibility afforded by the asbestos of the lining used gives, when the lining is properly installed, freedom from cracks. When used in 24-hour operation on the lower melting alloys, those high in zinc, which fortunately form a large proportion of the output of a brass rolling mill, this lining has a very satisfactory life, 1,000,000 lbs. being perhaps the average. One furnace was still going strong after melting 6,000,000 lbs. in one lining. These figures refer to alloys very low in lead. Even a lead content of 3 to 5% will reduce the life to something like a quarter of that in a lead-free alloy.

Since foundries generally handle alloys of 5% or higher lead, and seldom operate 24 hours a day, this type of furnace has not been found applicable to foundries save in rare cases. A lining that would stand up against lead and would not crack on heating and cooling would make this type of furnace more applicable to foundry conditions.

The refractory used in the Ajax furnace is quite satisfactory for rolling mill use on "high" brass, *i. e.*, brass high in zinc, but the lining which does so well there, does not do at all well when alloys on the high copper end of the scale, or when brasses containing nickel, *i. e.*, "nickel silver" or "German silver" are melted. It has recently been suggested by Stout¹ of the Phelps-Dodge Corporation that it might pay to finish the melting of cathode copper in the induction furnace. The rolling mills would like to be able to use the induction furnace on copper and alloys high in copper, but none of the linings so far tried have been fully satisfactory. One of the mills states that the development of such a lining would solve the most serious problem at present confronting users of the Ajax furnace.

Electrically sintered magnesite has been tried, and stands the temperatures and the action of the metals, but it cracks too readily. Chromite is now being tried out, but its performance is not fully satisfactory. Chromite has been tried in an electric brass furnace using electrodes and in which the furnace atmosphere is strongly reducing but the chromite was reduced too readily and the furnace wound up with a lining of ferrochrome instead of chromite.

The General Electric Co. has very recently brought out a slightly different form of the vertical ring induction furnace in which the lining is made of three large sections which when assembled and cemented together form the hearth proper and the resistor ring. This substitution of preformed and previously fired refractories is expected by the makers to allow the

¹ H. B. Stout, "One Phase of the Problem of Increasing the Consumption of Copper," *Mining and Metallurgy*, Nov., 1922, p. 15.

application of the induction furnace to those alloys which the Ajax-Wyatt has trouble with, but the G. E. furnace has been too recently put out for results from users' tests to be available.

There are many other types of electric furnaces for non-ferrous alloys, each of which has its own special refractory problems, sometimes so serious that those problems alone have held up all development of the type. Some of the problems are as interesting as those of the furnaces of commercial importance, but space forbids even touching on the few other types of furnaces that find slight use on copper alloys.

There are several possible lines of advance in refractories that might be of value for copper alloy furnaces in general and electric furnaces in particular. For thermal efficiency it is desirable to have a graded lining running from very refractory on the inside to the best possible heat insulator on the outside. Instead of using two or three layers, if the individual bricks were so graded from end to end, a more solid wall could be built. Quite a little experimental work has been done along these lines, but progress does not yet seem to have gotten to the point of commercial trial.

Another possibility is in the use of real refractories even though they be expensive. From his own laboratory experience with alundum, the writer would expect that a furnace with an inner lining of alundum brick would stand up for a very long time in a rocking furnace. Unfortunately when the writer was experimenting with a commercial sized rocking furnace in the early days of its development, it was not possible to buy enough such bricks at any price. Carborundum brick have proved to be worth their high price for many uses, but their heat conductivity is so high that a carborundum lining thick enough to be mechanically stable would generally involve either too high heat losses or too high heat storage in an electric brass furnace.

Zirconia refractories ought to be just the thing on account of their reputed refractoriness, resistance to penetration by metal, resistance to spalling and low thermal conductivity. The actual zirconia refractories that have been tried out, as far as reports have reached the writer, did not live up to their reputation. Nevertheless it is almost certain that when sufficient work has been done on zirconia, a real refractory will result.

Since metal tightness and resistance to spalling or cracking under change of temperature are so important, ordinary magnesite or silica has little promise. Since the highly aluminous fire brick are standard for a good many electric brass furnaces, it is quite likely that the new electrically prepared, pre-shrunk refractories of that type may be even better.

The user of an electric furnace is naturally rather coy about trying out a new refractory at around \$1.00 a brick without some assurance that

¹ See H. W. Gillett and E. L. Mack, "Electric Brass Furnace Practice," *Bull.* 202 U. S. Bur. Mines, 1922.

the increased life is going to be worth the price. But even such a price would not be impossible if the lining would really stand up. The first cost of a new lining is not so important as the loss of use of the furnace while it is down for relining. The maker of expensive refractories would find it a good investment to give away brick for trial linings if he really has something that will stand up, in order to establish records of long life in actual commercial use. Without such coöperation by the manufacturer the use of super refractories will be a matter of slow growth in these furnaces.

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SILICATE OF SODA IN THE CERAMIC INDUSTRIES

BY JAMES G. VAIL

ABSTRACT

The term "silicate of soda" is applied to a number of products of varying properties. Cements made with one variety ($\text{Na}_2\text{O} \cdot 2.4\text{SiO}_2$) as a binder have been widely used for mending saggers. The deflocculation of clay with silicate in connection with refining and casting has been studied but the advantages offered by the varieties of silicate have not been considered. This appears to be a fertile field for investigation. Another important use for silicate of soda ($\text{Na}_2\text{O} \cdot 2\text{SiO}_2$) is in the manufacture of abrasive wheels. Although this process is old, there is still much to be learned about it.

A consideration of silicate of soda in the ceramic industries or, for that matter, in any industry must be predicated on an understanding of what is meant by the term silicate of soda. In a commercial sense silicate of soda is not a more definite term than clay. Its connotation is general rather than specific. Attention must be called to this fact because in spite of a voluminous literature there are still many technical men who think of a definite sodium silicate when they see the syrupy liquid of commerce.

Sodium meta-silicate has been studied by several workers, notably Erdenbrecher, who has prepared three crystalline hydrates of Na_2SiO_3 with four, six and nine molecules of water, respectively. These may all be prepared at ordinary atmospheric temperatures. They all melt and lose their water of crystallization to liquids of low viscosity relative to the commercial preparations on the American market.

The ratio of Na_2O to SiO_2 is the usual index of the type of a commercial silicate solution. As the percentage and molecular ratios are so nearly alike custom has chosen the more convenient percentage ratio. This may vary between the 1:1 of the meta-silicate up to 1:4 or even higher. The properties of the products at the two ends of the scale are very different and any intermediate composition can be produced in general without sharp breaks in the curves which represent the changing characteristics. Although it is likely that a compound of the ratio 1:2 does exist its presence in the familiar solutions of this composition has not been completely proven. It is important then when you hear or read about silicate of soda to think—which silicate of soda?

Perhaps the use of silicate of soda for mending saggers is more widely applicable in the ceramic industries than any other. Where the break is a simple one, the process of repair is so simple as to be a marked economy. For this purpose a silicate which dries in the air to form a firm joint and retains its bonding quality as the temperature rises should be selected. An air dried silicate solution, even when they develop a bond strength above a thousand pounds per square inch, are hydrous. They can be completely de-hydrated only at kiln temperature. During the removal of the last few per cent of water the bond strength of most silicate solutions is much

duced. At temperatures near 2000°F sintering begins and the silicate again is sticky and has holding power. The ratio which we have found most suitable for this sort of work is about $\text{Na}_2\text{O}:\text{SiO}_2::1:2.4$. If a grade containing more silica is used, its strength will decline earlier with advancing temperature. If a more alkaline type be selected the cement will have a lower melting point and will set too slowly at atmospheric temperature. Silicate of soda should be mixed with a refractory clay to make the sagger mending cement. A mixture of calcined and raw clays is best though not essential. A wide variety of clays can be used. The silicate of ratio 1:2.4 is usually sold as a solution of about 47% solids testing 52° Bé. About two parts by weight of this and one part of powdered clay should be used. A little water may be added to permit mixing the cement to a smooth thick creamy consistency. It is best to paint both broken surfaces of the sagger with the cement taking care to apply enough to prevent a premature set due to absorption of water from the wet cement by the porous body of the sagger. This would occur only when the cement is spread very thin. Enough should be used to allow the cement to remain tacky for five minutes if exposed to the air. The broken parts should be pressed together so that a little is squeezed out and allowed to stand undisturbed over night. A joint formed in this way is usually stronger than the body of the sagger.

Cements made with clay and silicate of soda are also useful in making as tight brick work in kilns, boiler furnaces, coke ovens and the like. The influence of electrolytes on the suspension of clay in water as applied to refining and casting has received a great deal of attention and is the subject of a fairly voluminous literature. Beginning with a discussion of Acheson's paper on Egyptianized clay before this SOCIETY in 1904 when V. D. Gates called attention to a similar effect of silicate of soda on clay, members of the AMERICAN CERAMIC SOCIETY have made numerous contributions to our knowledge. Bleininger and Schurecht should be especially mentioned in this connection. It is worthy of note that much that has been written is either unclear or entirely silent as to the kind of silicate employed. All solutions of silicate of soda will indeed assist in the suspension of clays and up to an optimum concentration make the separation of other minerals easier. In each case amounts beyond the optimum concentration produce a lesser effect or cause the flocculation of the suspended clay. The work of Schurecht has shown that the effect of silicate is not merely the effect of a given amount of sodium oxide which may be added in any convenient form. A unit of Na_2O as sodium silicate has a larger effect in reducing the viscosity of a clay slip than the same amount of Na_2O added either as hydroxide or carbonate. The silica must enter into the reaction and it appears that a study of the various types of silicate with different ratios of $\text{Na}_2\text{O}:\text{SiO}_2$ would be a valuable contribution to our knowledge of

the art. The hydrogen ion concentration is certainly an important factor in the effect of electrolytes on clay suspensions; the different types of silicate provide a convenient means for securing the concentration suitable to the manipulation of each particular clay and the buffer effect of the silicate should make it more easy to control the characteristics of the slip or the suspension in the refining process.

The varieties of silicate of soda should also be studied with reference to their effect on the density shrinkage and strength of the ware. If one form of sodium silicate added to a clay in amounts of less than 2% based on a 40% solution can cause differences of more than 100% in the dry strength or the fired strength of clays it is a matter of concern to know whether the form arbitrarily chosen for the study was in fact the most suitable. We have abundant evidence that the various forms do not behave alike.

One of the oldest uses of silicate of soda is to form a bond for abrasive materials in the manufacture of grinding wheels and abrasive stones. The process is widely used and has numerous advantages important among which is the possibility of forming a wheel on one day and putting it into service the next. The silicate bond easily produces masses having a tensile strength of 2000 pounds per square inch and the loss in process is very small. The silicate ordinarily employed for wheel manufacture has a ratio of 1:2 and is concentrated to a very sticky solution containing about 54% solids. This solution is mixed with approximately an equal weight of a finely pulverized mineral such as clay or silica. The chemical characteristics of this powder can be varied considerably and good results secured but its fineness and the thoroughness with which it is mixed with the silicate solution and the abrasive grains are important. The tamping of the mixture into molds calls for experience and skill to produce a uniform body. The wheels are first air dried at temperatures below the boiling point of water for a length of time dependent on the size of the wheel and then baked at about 450° Fahrenheit for several hours. The chemistry underlying this process is not fully understood although a large amount of practical experience has developed a technique which gives good results. It is not, for instance, known that there is any reaction between the mineral filler and the silicate solution and yet wheels are made sufficiently resistant to water to be run wet.

The water resistance of some mixtures is, however, improved by the addition to the inert mineral of small quantities of oxides capable of reacting with the silicate at the temperatures used in the process. One of these is zinc oxide. Fundamental research on the reactions of the silicate in the abrasive wheel process is needed to understand what has been empirically found to be good practice and to point the way to improvements. We already know that a silicate of very different character from those used for adhesive purposes is required.

Whether it be the making of silicate cements for mending saggers and setting brick with gas tight joints, or the regulation of the flowing and suspension characteristics of mixtures of clay and water with small additions of silicate solutions, or the manufacture of quick process silicate abrasive wheels, the fact is worth remembering that the various forms of silicate have different properties. The grade best suited for one process may be quite unfit for another and many a process can be perfected by choosing a silicate solution adapted to the peculiarities of the clay with which it comes in contact and the conditions of its use.

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No. 5

CLAY SEWER PIPE MANUFACTURE

I.—The Magnetic Separation of Iron Bearing Minerals from Clays¹

BY H. G. SCHURECHT²

ABSTRACT

Purpose.—Experiments were conducted to remove coarse iron bearing minerals from clays magnetically in order to prevent their formation of black blisters on sewer pipe.

Results.—It was found that most of the coarse iron bearing minerals can be removed by means of a high intensity magnetic separator. Although the cost of this treatment on the roasted clays is too great, the separation from the raw material is not prohibitive to plants suffering large losses due to this defect.

Introduction³

The requirements for sewer pipe are very rigid since they must not only be strong but also resistant to chemicals. At present sewer pipe made

¹ Published through the courtesy of The Easter Clay Products Association and The Clay Products Association under whose auspices this work has been conducted as a part of their research program on the manufacture of clay sewer pipe.

This is the first of a series of papers on this subject to appear in this *Journal*.

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³ The writer wishes to acknowledge his indebtedness to Dr. E. W. Tillotson, Assistant Director of The Mellon Institute, for helpful advice during the progress of the work and to the Magnetic Separator companies for their coöperation in this work.

of clay is the only kind which meets the most important of these requirements. New specifications for sewer pipe are being made from time to time and in order to keep pace with these, this research is being conducted to improve the quality of clay sewer pipe. The possible methods of removing iron bearing minerals from clays are being investigated as a part of this program. Coarse particles of iron bearing minerals and clay particles containing a high content of iron oxide cause rough, black blisters on the glazed ware. The removal of particles causing these would not only improve the quality but also reduce the losses in their manufacture.

The most important of the iron bearing minerals producing this roughness are siderite, hematite, limonite, marcasite and pyrites.

Siderite, FeCO_3 , is by far the most abundant of these in sewer pipe clays. It often occurs in bands in clay banks or as nodules, mixed with or

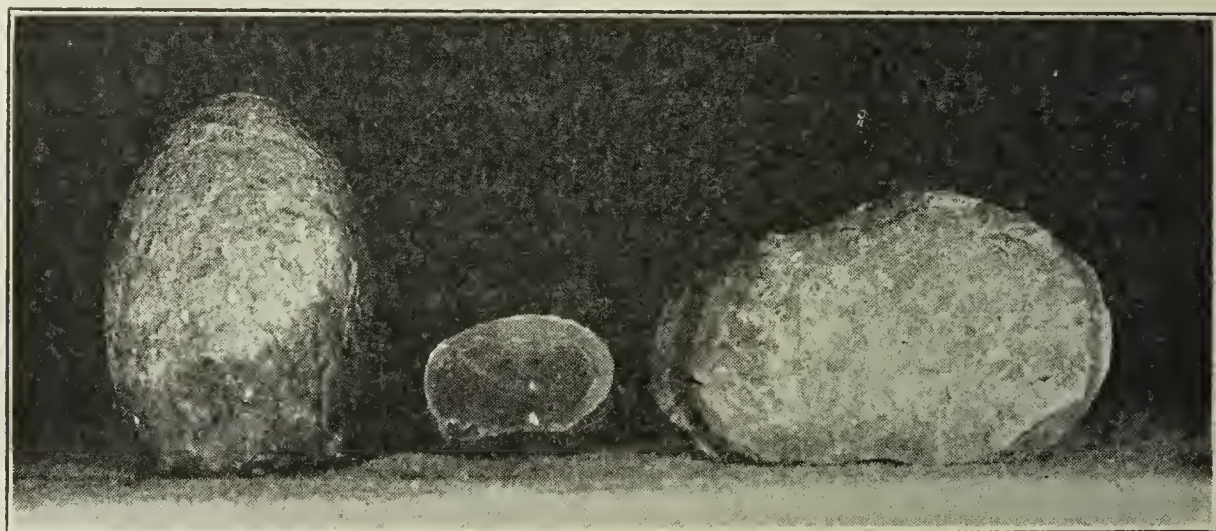


FIG. 1.—Nodules of siderite as they occur in clays.

without clay, which are commonly known as “kidney balls,” see Fig. 1. The size of these nodules may vary from about one foot to $\frac{1}{16}$ inch in diameter.

Pyrite, FeS_2 , usually crystallizes in the form of cubes and has a brass yellow color. Marcasite has the same composition as pyrites but forms different crystals, has a paler color and decomposes easier.

Limonite, $2\text{Fe}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$, and hematite, Fe_2O_3 , are usually present in a fine-grained state mixed with the clays. They are often decomposition products of siderite, marcasite and pyrites.

Since most iron bearing minerals are magnetic to a certain degree and since clay particles containing an excess of certain iron bearing minerals are also magnetic, the separation of these by this method seemed worthy of investigation. A study was therefore made of this subject which has progressed far enough to show that the major portion of the coarse iron bearing minerals and clay particles containing too much iron oxide may be removed with a high intensity magnetic separator.

The Magnetic Properties of Some Iron Bearing Minerals

Generally speaking the magnetic susceptibility of the various iron bearing minerals as they occur in clays, decrease in the following order:¹

Magnetite.—This mineral is very magnetic being about 65 per cent that of tempered steel and may be separated with a low intensity magnet.

Siderite.—Siderite is slightly magnetic, being about 0.1 per cent that of tempered steel and may be removed with a high intensity magnet.

Hematite.—This mineral is feebly magnetic and may be separated with a high intensity magnet.

Limonite.—Limonite is feebly magnetic and may be removed with a high intensity magnet.

Marcasite and Pyrites.—These minerals are usually non-magnetic, although sometimes they are feebly magnetic and in these cases can be separated with a high intensity magnet. They, however, become magnetic if slightly roasted and may then be removed with a low intensity magnet.

As a rule coarse grains of magnetic substances may be more easily removed than fine grains of this material, since fine grains usually have a larger percentage of non-magnetic material adhering to them and hence a greater magnetic force would be necessary to remove them.

Operation of Some Magnetic Separators

A Low Intensity Magnetic Separator.—This separator is used for removing highly magnetic substances from granular material. It cannot be employed for separating the commoner iron bearing minerals from raw clays although it may be used for removing iron bearing minerals from roasted clay.

The magnet consists of a large stationary primary magnet body and a series of small secondary induced magnets mounted upon a rotating disk. The primary magnet is held solidly in a fixed position and has heavy double coils and cores with pole pieces projecting downward and conforming to the circle of the disk. The secondary magnets are inductively energized by the primary magnets when over the clay on a conveyor, but become demagnetized as they leave the proximity of the primary poles and automatically discharge any iron or magnetic material they may have attracted, allowing it to drop at the points on the sides where the disk overhangs the conveyor. The magnetic material is conveyed by chutes into a box or receptacle. The non-magnetic material passes off at the end of the conveyor to final delivery.

High Intensity Magnetic Separator (Type A).—The high intensity magnetic separator, type A, can be used for removing the commoner iron bearing minerals from clays.

¹ C. Godfrey Gunther, "Electro-Magnetic Ore Separation," Hill Publishing Co., N. Y. (1909).

The dry material to be treated drops from the hopper onto the feed roller, which spreads it in a thin uniform layer over the whole width of the conveyor belt, as it travels towards the poles of the magnetic system. The poles consist of two horseshoe electro-magnets, arranged one above the other. The poles of the upper magnet are forged in the form of a short wedge while the lower ones are flattened. This principal is characterized as "sharp against flat," and it is the high magnetic concentration on the upper pole, caused by the conveying field, which enables this separator to treat very weakly magnetic materials. The magnetic force of the upper wedge-shaped pole superceded that of the lower, so that as the clay on the conveyor belt passes between the first poles of the magnets, the magnetic particles are attracted towards the upper poles, and jump toward it. They are intercepted, however, and prevented from reaching the upper pole by the cross-belt which removes them quickly from the field and influence of the magnets and allows them to drop into a receptacle provided at one side.

High Intensity Magnetic Separation (Type B).—The separation of iron bearing minerals from clays is accomplished with the B high intensity separator with a gradual step by step process. The material moves from pole to pole of progressively increasing intensity which is made possible by independent adjustments of each magnetic gap and by accurate control of the current flow to the coils. As the material is conveyed to the take-off rings, it passes through a strong magnetic field which overcomes a considerable amount of reluctance before reaching the intense magnetic gap where the separation takes place. The first gap of the magnet, which is usually greater than the second, removes the stronger magnetic particles. This also partly overcomes the reluctance of the feebly magnetic materials and makes them more susceptible to the influence of the closer adjusted gap of the second pass, resulting in a better separation.

Experimental Methods.—Ten kilogram samples of two raw ground sewer pipe mixtures, screened through a 10-mesh sieve were treated with a low intensity magnetic separator and the two high intensity magnetic separators, types A and B.

The portions removed by the magnet as well as the non-magnetic portions were molded into cones and fired at a temperature corresponding approximately to that at which sewer pipe are fired. The appearances of the magnetic portions after firing were then noted.

Similar experiments were conducted on the same clays after roasting at a dull red heat for comparison, since it is claimed that the magnetic susceptibility is increased by roasting.

Experimental Results.—The results given below represent the percentages removed magnetically by machines of greater and greater strength as the ground clay was passed through them successively. The non-

magnetic portion is that unaffected by the magnetic treatment and, therefore, represents the purified clay.

TABLE I

Treatment of raw clay 1.23 with type A high intensity magnetic separator with 220 volts and the belt moving at a speed of 60 feet per minute.

Magnetic intensity	Weight, grams	Portions separated, per cent	Amperes	Gap, inches
Medium high.....	250	2.5	1	$\frac{3}{8}$
Extreme.....	310	3.0	$2\frac{1}{2}$	$\frac{3}{8}$
Non-magnetic.....	9600	94.5	$2\frac{1}{2}$	$\frac{3}{8}$
Total.....	10160	100.0		

TABLE II

Clay 1.23, roasted at a dull red heat for 3 minutes, and treated with a type A high intensity magnetic separator, with 220 volts and with the belt moving at a speed of 60 feet per minute.

Magnetic intensity	Weight, grams	Portions separated, per cent	Amperes	Gap, inches
Medium.....	1920	27.8	...	$\frac{3}{16}$
Medium high.....	2040	29.6	1	$\frac{3}{8}$
Extreme.....	1320	19.1	$2\frac{1}{2}$	$\frac{3}{8}$
Non-magnetic.....	1620	23.5	$2\frac{1}{2}$	$\frac{3}{8}$
Total.....	6900	100.0		

The portions separated as well as the purified clay are shown after firing in Fig. 2. The cone marked 1 represents the portion removed from

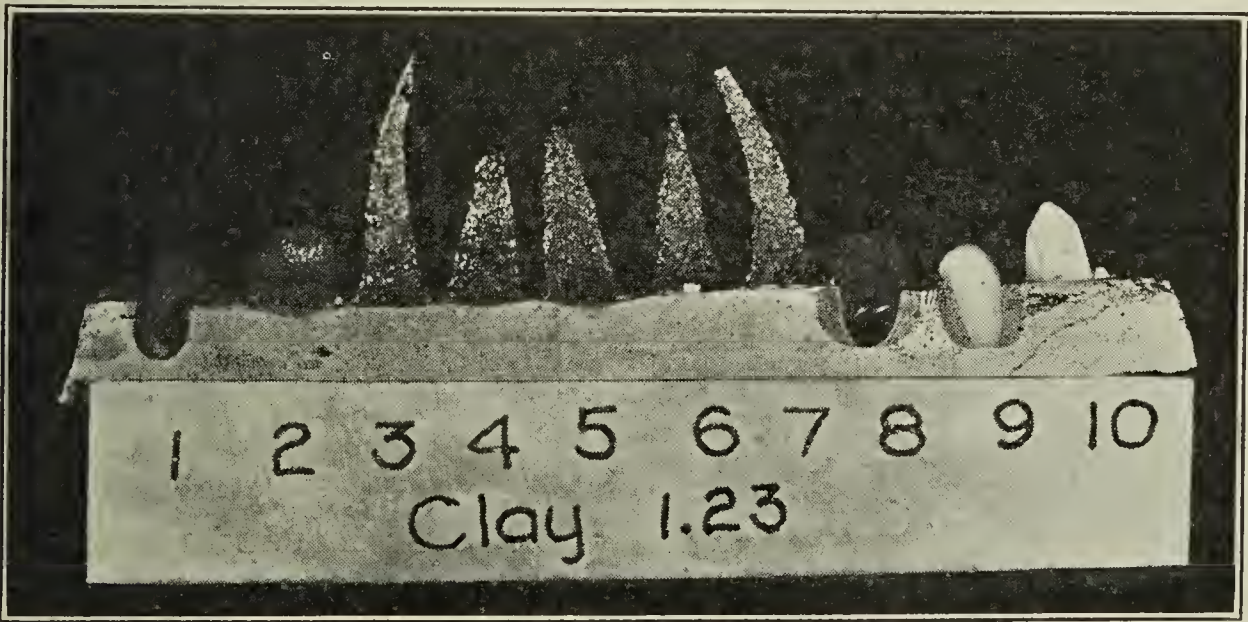


FIG. 2.—Portions separated with a magnet and purified clay after firing.

the raw clay 1.23, with a medium high intensity. Cone 2 represents the portion removed with an extreme magnetic intensity and cone 3 the purified clay (see Table I). Cones 1 and 2 fused to a black slag due to a high con-

tent of iron compounds, which they contain, while the purified portion, cone 3, is practically free from coarse iron blister, with the exception of a few small black spots.

The cone marked 4, see Fig. 2, represents the portion separated from the roasted clay 1.23 with a medium magnetic intensity, see Table II. Cone 5 represents the portion removed with a medium high intensity magnet. Cone marked 6 represents the portion removed with an extreme magnetic intensity and cone 7 represents the portion which was non-magnetic. Although cones 4, 5, and 6 are darker than cone 7, due to their higher content of iron compounds, the cones retained their shape and did not fuse to a slag as cones 1 and 2 did, indicating that the portions separated from the raw clay contained a larger per cent of iron compounds than that separated from the roasted clay.

Cones marked 7, 8, and 9 represent Seger cones 1, 4, and 8, respectively. These samples were fired to cone 8. It is apparent that portions 1 and 2, separated from the raw clay, would cause roughness on pipe if fired to this temperature and that removing this magnetic portion from the clay would produce a pipe of better finish.

The results obtained on clay 1.09 are given in Tables III and IV below.

TABLE III

Treatment of raw clay 1.09 with a type A high intensity magnetic separator with 220 volts and with the belt moving at a speed of 60 feet per minute

Magnetic intensity	Weight, grams	Portions separated, per cent	Amperes	Gap, inches
Medium high.....	40	0.4	1	$\frac{3}{8}$
Extreme.....	80	0.9	$2\frac{1}{2}$	$\frac{3}{8}$
Non-magnetic.....	9120	98.7	$2\frac{1}{2}$	$\frac{3}{8}$
Total.....	9240	100.0		

TABLE IV

Clay 1.09, roasted at a dull red heat, and treated with a type A high intensity magnetic separator with 220 volts and with the belt moving at a speed of 60 feet per minute

Magnetic intensity	Weight, grams	Portions separated, per cent	Amperes	Gap, inches
Medium high.....	80	1.1	1	$\frac{3}{8}$
Extreme.....	100	1.3	$2\frac{1}{2}$	$\frac{3}{8}$
Non-magnetic.....	7200	97.3	$2\frac{1}{2}$	$\frac{3}{8}$
Total.. ..	7380	99.7		

The portions separated as well as the purified clay are shown after firing in Fig. 3. The cone marked 1 represents the portion separated from the raw clay 1.09 with a medium high intensity (see Table III). Cone marked 2 represents the portion removed with an extreme magnetic intensity and cone 3 represents the purified clay. Cones 1 and 2 fused to a black slag due to the high content of iron compounds which they con-

tain, while the purified clay, marked 3, is practically free from coarse iron specks with the exception of a few small black spots.

The cone marked 4 represents the portion separated from the roasted sample of clay with a medium high intensity (see Table IV). The cone 5 represents portion B removed with an extreme magnetic intensity and cone 6 represents the portion which was non-magnetic. Cone marked 4 fused to a black slag due to the high content of iron compounds which it contains. Cone 5 contains a considerable amount of iron compounds as is shown by its black color but the content of iron in this instance was not sufficient to cause it to deform as was the case with cone 4. The purified

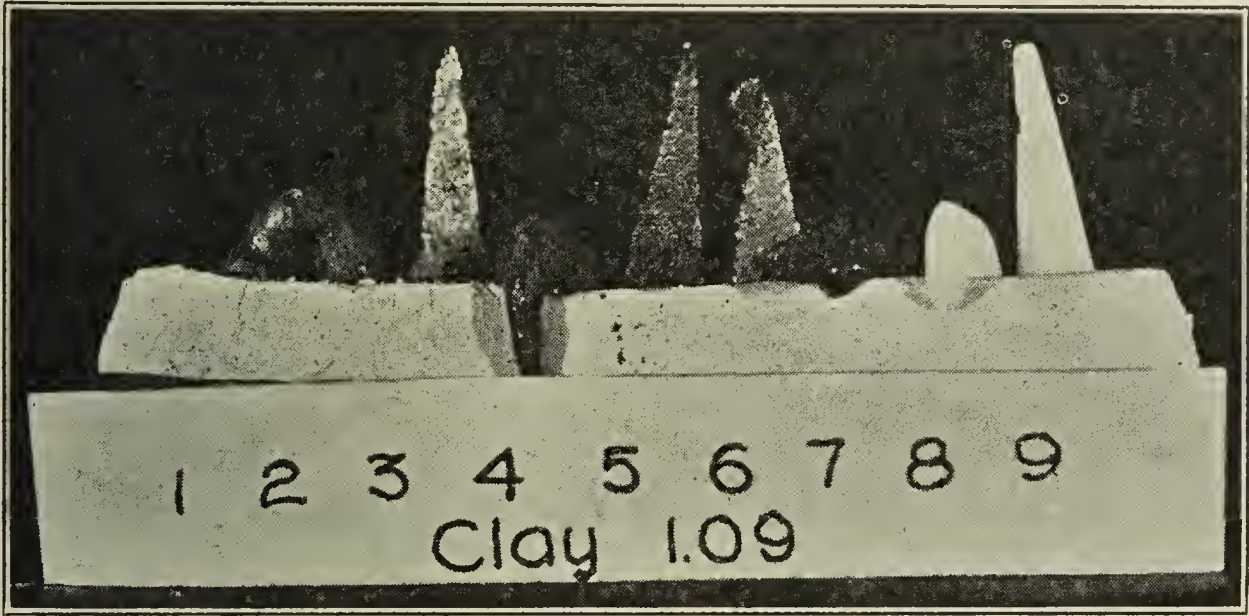


FIG. 3.—Portions separated with a magnet and purified clay after firing.

cone 6 contained practically no coarse iron specks. In this case again it appears that the portion separated from the raw clay contains a greater percentage of iron oxide than that removed from the roasted clay.

The cones marked 7, 8, and 9 represent Seger cones 1, 4, and 8, respectively. These samples were fired to cone 4. In this case it is again apparent that the magnetic portions 1 and 2 would cause roughness if they were present in a sewer pipe body fired to this temperature and that pipe of better finish may be produced by the electromagnetic separation of the iron bearing minerals from the clay previous to molding.

The results obtained with the high intensity magnetic separator type B on the same clays as were tested above are given in Tables V and VI below.

TABLE V

Treatment of raw clay 1.23 with a type B high intensity magnetic separator.

	Magnetic intensity	Weight, grams	Portions separated, per cent
Extreme.....		22.0	2.23
Non-magnetic.....		956.0	97.75
Total.....		978.0	99.98

TABLE VI

Treatment of raw clay 1.09 with a type B high intensity magnetic separator.

	Magnetic intensity	Weight, gram	Portions separated, per cent
Extreme.....		4.0	0.55
Non-magnetic.....		724.0	99.45
Total.....		<hr/> 728.0	<hr/> 100.00

The portions removed with this separation fused to a black slag when fired to cone 3 appearing similar to those portions removed with the type A separator.

The separator A, however, removed a higher percentage of iron bearing minerals from the clays than the separator B. The results obtained with the high intensity magnetic separator B are about the same as were obtained with the medium high intensity separator A.

Summary and Conclusions

Tests were made on ground clays to determine if the coarse iron bearing minerals which cause roughness on sewer pipe may be separated with a high intensity magnetic separator. The laboratory tests indicate that it is possible to remove considerable of the coarse iron bearing minerals by such a separation. The expense of this treatment is not prohibitive to plants sustaining large losses due to this defect, and in some cases it may not only improve the ware but also reduce the cost of manufacture.

CAPPING FOR COMPRESSION SPECIMENS¹

BY HARRY D. FOSTER

ABSTRACT

Compressive strength tests have been made on tile capped with unretarded gypsum with neat Portland cement, with a mixture of three parts by volume of Portland cement to one part of unretarded gypsum and on tile whose bearings were ground. The tile whose bearings were ground gave the highest strengths. The interpretation of the results was based on the workability and yielding of the cap and on the influence of the bearing block. As it is impossible to grind the bearings of all types of tile, a cap of three parts of Portland cement to one part of unretarded gypsum is advocated as giving the highest and most consistent results.

A survey of the methods of testing hollow tile in compression shows that many testing laboratories use for caps a plastic mortar of calcined gypsum (plaster of Paris), while others use a mixture of calcined gypsum and Portland cement, or in some cases neat Portland cement whose set has been accelerated. This condition may be in part responsible for the variations in strength and for the many discrepancies which are constantly arising in connection with testing of tile. In order to obtain some data which would help to clear up the situation and on which a more definite method of making compression tests can be based, the present series of tests was undertaken. The results show that the strengths obtained depended to some extent on the cap. With very soft caps which flowed freely lower strengths were obtained than with fairly hard caps of material that had a proper degree of workability.

The tile used were all of the 6-cell end construction type from a plant using typical Ohio fire clay and were tested with load applied parallel with the cells. The gypsum was unretarded and had a time of set of 18 minutes and a normal consistency of 50%. The Portland cement had a time of initial set of 5 hours and 15 minutes and a final set of 8 hours and 10 minutes, with a normal consistency of 22%.

In order to determine the age at which tile capped with each of the materials or with a combination of them, should be tested, 2-inch cubes were made and tested in compression at ages ranging from 20 minutes to 7 days. As shown in Figure 1, the neat gypsum attains a large proportion of its maximum strength within a few hours, a very rapid gain obtaining within the first hour. The cement and gypsum mixtures were very weak at early ages but the increase in strength was fairly uniform after the first 8 hours, reaching the full strength of gypsum in about 3 days. The neat Portland cement did not develop appreciable strength in less than one day. Its increase thereafter was very rapid, at 7 days being 4807 lb. per sq. in. After making a study of this plot it was decided to make compression tests

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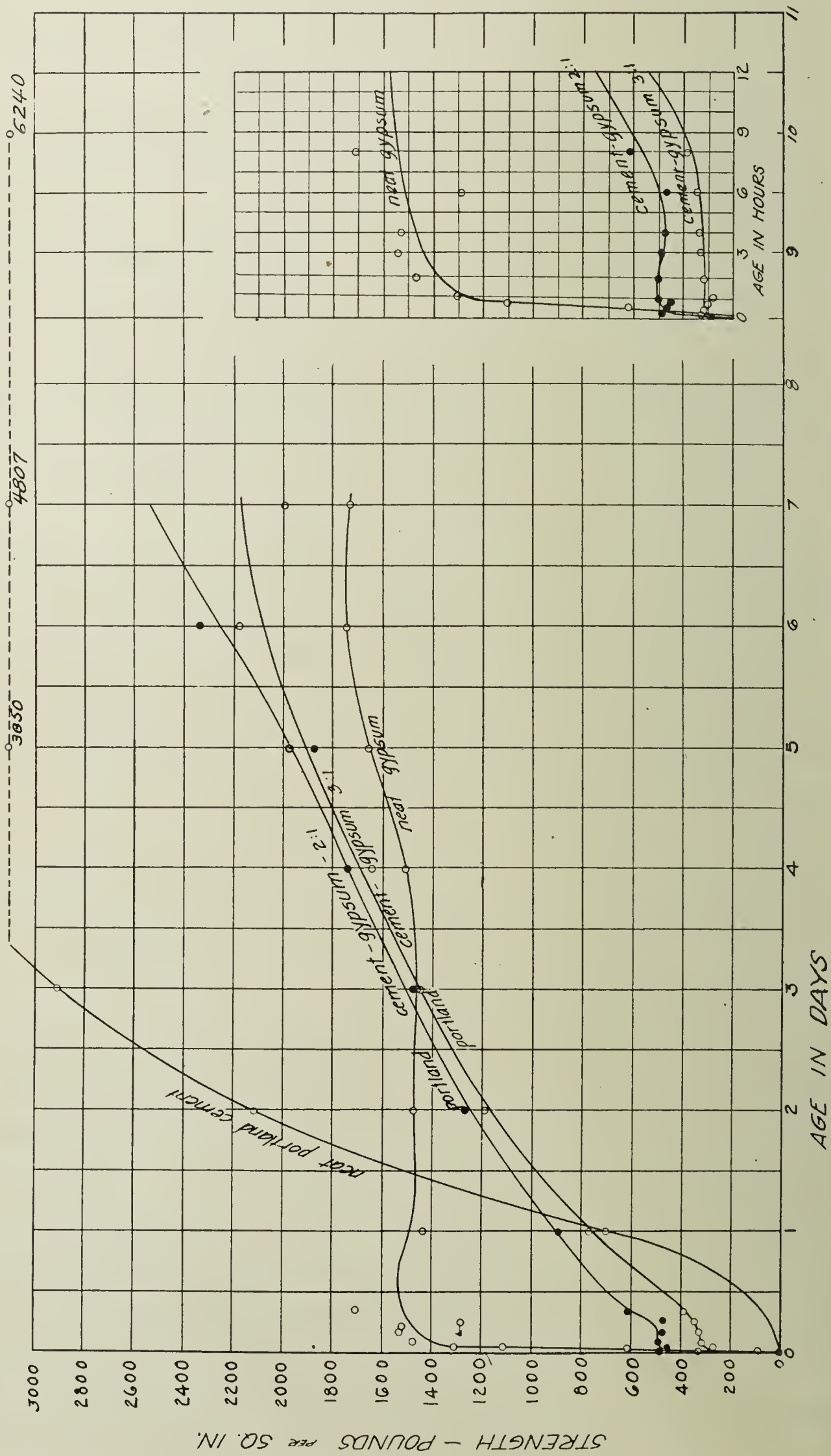


FIG. 1.—Compressive strength of two-inch cubes of the various capping materials used.

of tile when capped with neat gypsum at the ages of 1 hour and 3 hours; of tile capped with a mixture of three parts by volume of Portland cement and one part of gypsum at ages of 1 hour, 3 hours, 3 days and 7 days; and of tile capped with neat Portland cement at the age of 10 days. From the standpoint of workability any of these materials, except, possibly, neat Portland cement, could be used in capping tile. The neat gypsum and the mixtures of cement and gypsum gave early initial sets so that a capped tile could be removed from the capping block within 15 minutes after the cap was made. The cement, however, did not set sufficiently to allow the tile to be moved for 6 to 8 hours.

After coating the bearing surfaces and adjacent parts with shellac to keep the tile from absorbing water from the plastic cap, they were capped in the following manner: A quantity of the capping material mixed with enough water to give it a consistency slightly exceeding the normal was spread on a glass plate which had been moderately coated with oil. One bearing surface of the tile was then set in this plastic material and while holding the axis of the tile as nearly vertical as possible, a single and firm pressure was applied. As soon as this cap had hardened sufficiently so that the tile could be moved, the other bearing surface was capped. The caps were $\frac{1}{16}$ to $\frac{1}{8}$ inch thick. No caps were patched, imperfect ones being replaced with new ones.

The tests were made in a 300,000 pound Riehle testing machine, the speed of the moving head being slightly less than 0.05 inches per minute. The load was applied continuously, readings of the compressometer and measurements of the distance traveled by the moving head being taken at

loading increments of 500 pounds per square inch of net sectional area of the tile. By taking the distance traveled by the moving head with reference to the fixed head with an Ames gage, the total deformation of the tile and cap was obtained. Then as the deformation of the tile was measured with the compressometer, the deformation or flow of the cap was readily calculated.

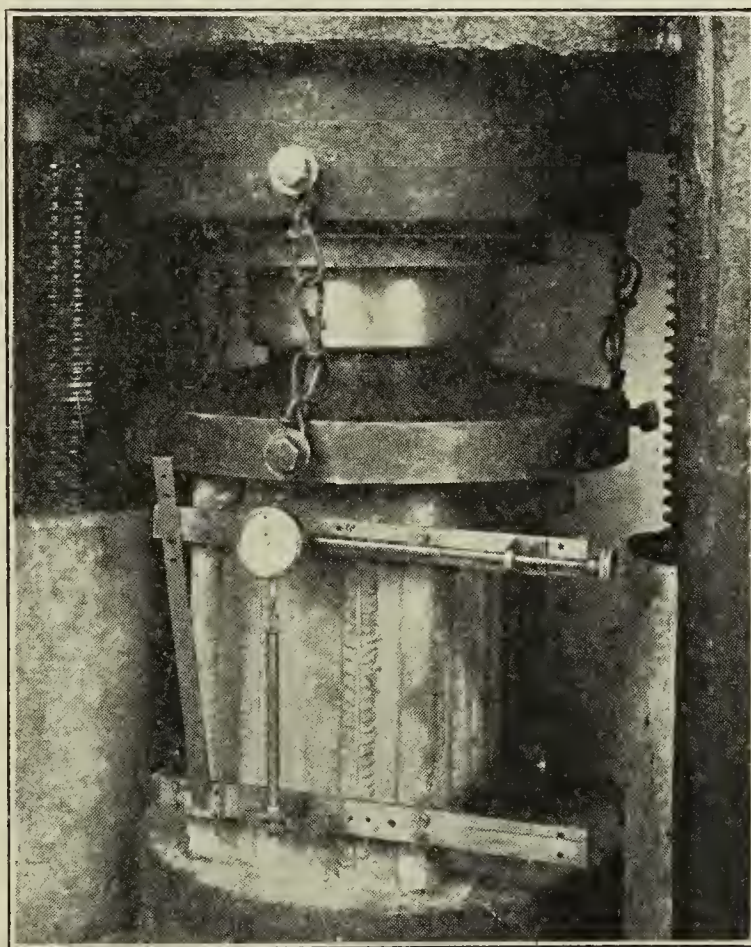


Fig. 2.—Bearing block and compressometer used in compression tests

The bearing block and compressometer used are shown in Figure 2. The center of the spherical bearing surface is located approximately in the lower plane surface of the block.

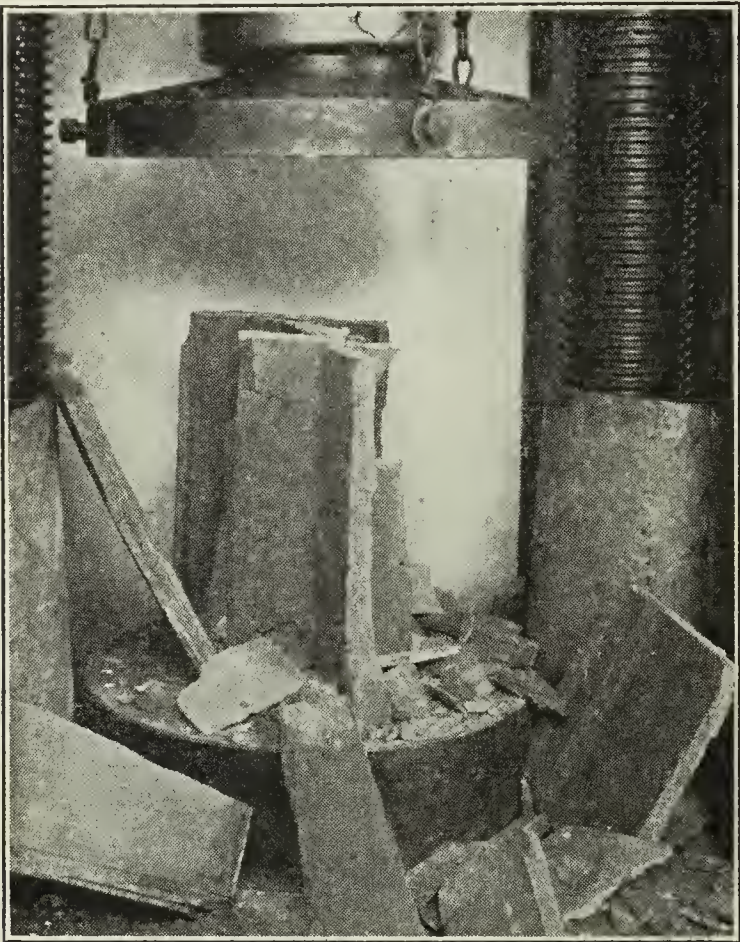


FIG. 3.—Tile after compression tests showing a typical failure.

By carefully centering the tile and rotating the top member of the bearing block as the moving head of the machine was lowered no difficulty was encountered in obtaining consistently good failures typical with that of Figure 3.

Representative pieces of tile were selected after each compression test for absorption determinations and the results from strength tests of the tiles which were appreciably above or below the absorption average were discarded. This left tile having nearly uniform absorption from which all the results summarized in Table I were taken.

From the curve given in Figure 4 it is seen that in all cases the deformation of the cap was appreciable and with some materials larger than that of the tile. It is noted that the mixture of Portland cement and gypsum at early ages deforms very rapidly from the beginning of the test and is apparently un-

TABLE I

Capping material	Age when tested	No. of tests	Average max. load in lbs. per sq. in. of net sectional area	Average percentage absorption	Relative strength
Neat gypsum	1 hour	8	5824	9.24	0.884
	3 hours	6	5913	8.94	0.897
3 parts of Portland cement to 1 part of calcined gypsum	1 hour	7	5778	9.03	0.876
	3 hours	6	5756	9.55	0.873
	3 days	7	6176	9.18	0.936
	7 days	9	6593	9.14	1.000
Neat Portland cement	10 days	6	6107	9.09	0.926

suitable for use as capping material at these ages. At three days and seven days, however, this cap did not deform greatly. The deformation of the neat gypsum cap was not excessive up to loads of 1000 to 1500 lbs. per sq. in., when it weakened and began to show a decided flowing. The deformation and flow of the neat Portland cement cap was very gradual,

the deformation curve, after initial adjustments had taken place, being nearly a straight line up to the point where the instrument was taken off.

From Table I it is seen that a cap of three parts of Portland cement and one part of gypsum at the age of seven days gives the highest strength for hollow tile; that neat gypsum or the cement-gypsum mixture at 1 and 3 hours gives results averaging about 89 per cent of those obtained with the mixture at 7 days; and that the mixture at 3 days gives results almost equivalent to those obtained with neat Portland cement at 10 days.

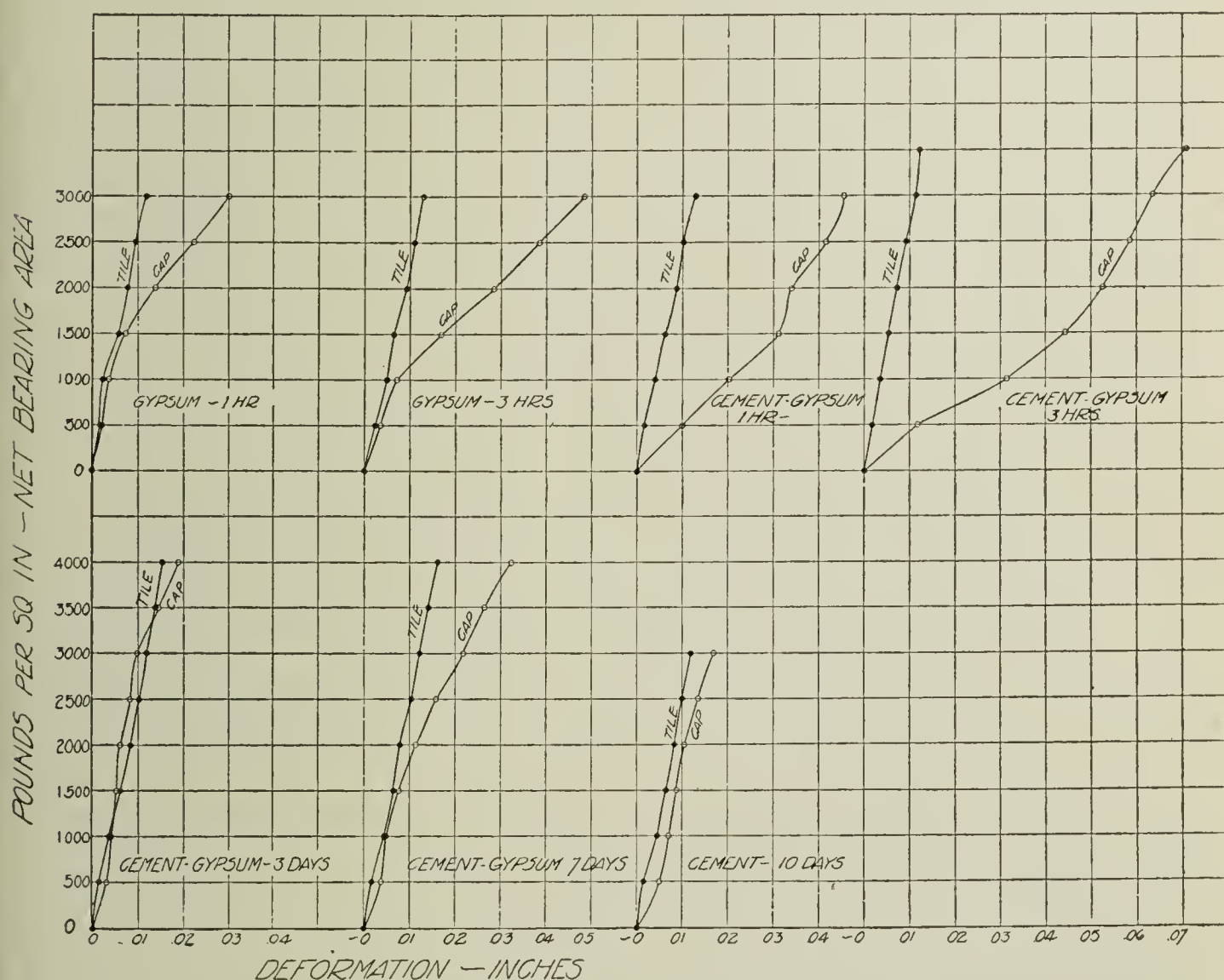


FIG. 4.—Average deformation of tile and caps from compression tests of tile.

The strengths developed with the various caps can be explained from the relative strengths and other properties of the capping materials and the deformation curves. With the softer caps and with the neat Portland cement cap, popping sounds due to adjustments at high spots were heard at earlier periods of the test than when caps of the mixture at 7 days were used. In the case of the Portland cement caps this behavior and the lower tile strengths attained than with the weaker 3:1 capping mixture, can be attributed to the more yielding consistency of the neat cement on the capping plate, the weight of the tile cutting through the capping material leaving only a very thin layer under the high points. The cement and

gypsum mixture attained a set in a minute or two sufficient to support the tile at all points.

Since making the above tests, another series of tests of 8 by 12 by 12 end construction tile has been made, about half of the number being capped with the 3:1 cement-gypsum mixture and the remainder having bearing surfaces ground smooth by means of a Dory type of grinder. The nine capped tile with an average absorption of 8.3% gave a strength of 6694 pounds per square inch of net sectional area, and ten tile with ground bearings having an average absorption of 8.7%, gave an average strength of 7426 pounds per square inch. This is an increase of 10.8 per cent obtained by grinding the bearings, which does not fully represent the gain in strength due to the slight difference in hardness of the two lots, as indicated by the absorption. In the tests with ground ends no popping sounds were heard until near the maximum load. It is difficult to state whether this increase was due wholly to more uniform bearing or due in part to greater lateral restraint at the bearing surfaces, some flow with consequent allowance for lateral expansion of the vertically compressed tile being incident with all capping materials used, particularly at loads near failure. That the effect of restraint at the bearing surfaces in increasing the strength of tile is probably not large may be concluded from results of tests of similar tile in 6-inch and 12-inch lengths. In tests covering a wide range in clay, 24 half tile having an average absorption of 13.91% gave an average compressive strength of 3988 pounds per square inch of net area, as against 3867 pounds per square inch for a similar lot of whole tile having an average absorption of 10.87%. It is apparent that for tile 8 to 12 inches in lateral dimensions, neither length allows for the full free action of the resultant shearing forces that are concerned in compression failure, which conditions, combined with possible restraint at the bearings, make the so-called true strength unattainable in compression tests of units of the sizes manufactured. That such strength may be no higher than that obtained with available methods of testing follows from the above consideration, even after making allowance for incidental eccentricities of loading. In the tests a well proportioned spherical steel block was used, that was carefully centered. In the tests of tile with ground bearings the average range between high and low values for tile of the same percentage absorption was about 13 per cent, only part of which should be attributed to eccentricity of loading, the other being due to variations in the tile. Results of tests with capped tile indicate variations of no larger amount and justify the belief that errors attributable to uneven bearings, bending and eccentric application of load can be kept down to limits where they are not of serious consequence.

The hydraulic bearing, while making possible adjustment of inclination of bearing surfaces during test, cannot be made practically adjustable

for irregularities of the bearing surfaces of the specimens sufficient to avoid capping or grinding the bearing ends. In attempts so far made in this direction a yielding material such as rubber has been used on the contact surfaces, which, with its high ratio of lateral expansion to longitudinal compression, induced lateral tension stresses and consequent splitting of the specimen on longitudinal planes, an effect much more disturbing and foreign than the lateral restraint incident with solid bearing contacts. An ideal bearing material should expand the same laterally on its bearings with the specimen for a given unit load as the specimen itself, and at the same time be yielding enough to adjust itself to the irregularities of the bearing, two conditions that one material cannot generally fulfill. The methods that can be recommended as standard procedure therefore comprise the use of metal bearings, and capped ends for the specimens, not many laboratories having the necessary grinding equipment, also, tile tested with cells horizontal cannot generally have their bearing surfaces trued by grinding without material weakening. The tests show that consistent and high results can be attained with caps of a mixture of 3 parts Portland cement and 1 part gypsum, aged 7 days.

The time necessary for aging a cap is generally available for acceptance tests since they are usually made before the shipment leaves the factory, samples being selected and sent to a testing laboratory. In cases where immediate tests are required, a cap made of unretarded gypsum of the required strength and aged not less than one hour should be used, as giving the highest strengths at the given age, although lower than those that would be obtained with the cement-gypsum mixture aged for a longer period.

The results obtained in this investigation apply generally to end construction tile with some possibility of changes in relative values for tile differing markedly in strength from those tested. For other material and shapes of test specimen, the results will not apply quantitatively although the variations will probably be in the same general direction.

The work which supplied the results herein given is a part of a general investigation of the fire resistance and related properties of hollow tile conducted at the Bureau of Standards in coöperation with the Hollow Building Tile Association. Acknowledgment is due to S. H. Ingberg, in charge of the Bureau's fire resistance work, for aid in planning the investigation and interpreting the results.

RESEARCH ASSOCIATE
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WASHINGTON, D. C.

SOME NOTES ON THE MEASUREMENT OF TRANSLUCENCY OF CERAMIC BODIES¹

BY CULLEN W. PARMELEE AND ROY E. LOWRANCE

The measurement of the translucency of pottery bodies has generally been done by methods which have been unsuited for obtaining exact data. Examples of these are the methods described by Ashley, Ogden and others² in the *Transactions of the American Ceramic Society*. Briefly these depend upon the determination of the maximum thickness of a test piece which permits the shadow of a wire or wire mesh to be visible to the naked eye, if the wire or wire mesh is interposed between the test piece and the source of light. The relative translucencies of the test pieces are thus based upon the order of maximum thickness of the same. In other words it is not much more satisfactory than the age-old method of observing the shadow of one's finger when it is placed back of a dish held in a strong light.

Priest³ has suggested a more exact method in which a photometer was used. Insofar as we know, the process has not been used. In *The Pottery Industry*,⁴ the results obtained by the use of a photometer in which a standard lamp was employed are given. Details of the method are not recorded.

The most complete investigation yet reported is that recently published by Steger.⁵ He used a photometer of the Bouguer type. His results are relative since they are always referred to certain test pieces which he adopted as standards.

During the past year some experimental work¹ has been carried on in the laboratory of the Department of Ceramic Engineering, University of Illinois, in which a photo-electric cell has been employed. The results which were obtained are regarded as important as indicating the practicability of this apparatus, yet we are not prepared to publish the results of the study of the bodies, because we are desirous of rechecking them, which work is now in progress.

The principle involved in the use of the photo-electric cell is that ultra-violet light, if allowed to fall upon a metal surface causes it to become elec-

¹ The following paper is based upon the results obtained by the junior author in the use of this method in the preparation of a thesis to meet the requirements for the degree of B.Sc. in Ceramics, at the University of Illinois.

² Lester Ogden, "Effect of Composition on the Strength of Porcelains," *Trans. Amer. Ceram. Soc.*, **13**, 400 (1911); Charles Weelans and H. E. Ashley, "Rept. of the Comm. on Classification of Whiteware," *ibid.*, **13**, 102 (1911); C. W. Parmelee and G. H. Baldwin, "Talc as a Body Material," *ibid.*, **15**, 532 (1913); A. S. Watts, "The Use of Mixed Potash-Soda Feldspars in Porcelains," *ibid.*, **16**, 212 (1914); C. C. Lin, "A Study of High Fire Porcelain," *Jour. Amer. Ceram. Soc.*, **2** [8], 622 (1919).

³ Irwin G. Priest, "The Bureau of Standards Contrast Method for Measuring Transparency," *Trans. Amer. Ceram. Soc.*, **17**, 150 (1915).

⁴ *The Pottery Industry*. Dept. of Commerce, Misc. Series **21**.

⁵ Steger, *Ber. D. Keram. Gesell.*, **2** [1], 9 (1921).

trically charged, and ions are set free which move toward the other electrode. The direction of the movement of the current will depend upon the nature of the charge. It has been found that the alkali metals are very sensitive to the influence of wave lengths of light within the visible spectrum. The apparatus which has been devised for use for the study of this phenomenon consists of a glass tube, the interior of which is coated with a layer of a metal. The tube is then evacuated and recharged with a small amount of argon gas and then sealed. If potassium is the metal used in such a cell it will be as sensitive to blue light as the human eye in its most sensitive condition. The blue light will impart 3×10^{-7} erg per second per sq. cm. of potassium surface exposed¹ producing a measurable photo-electric current of 5×10^{-15} amp. It has been found that if disturbing effects are absent, the relation between the total photo-electric current and the intensity is a linear one, and a strict proportionality exists between the intensity of illumination and the number of electrons emitted. This proportionality holds for light feeble as 3×10^{-9} erg per sq. cm. per sec. for blue light, and 2×10^{-7} erg per sq. cm. per sec. of orange light. The former value² is below the "threshold" value for the human eye. This holds over a wide range of illumination, from that which is too feeble to be visible to the eye to an illumination which is comparable to the light of the sun. Owing to the fact that a photo-electric cell is so sensitive to the influence of light, it has found use in many ways; for example, in radiometry, light intensities of smaller order of magnitude may be studied than is possible with a thermopile. The photo-electric cell is also used for the study of luminescence, for measuring the rapidity of photographic shutters, the decay of phosphorescence, and it has been used very successfully in the study of the light phenomena associated with solar and lunar eclipses.

The rate at which these electrons are emitted from a metal surface is influenced by certain conditions which need not be discussed. It is sufficient to say that these conditions can be maintained under sufficiently close control so that the apparatus is entirely practical for use by persons of limited laboratory experience.

The operation of the photo-electric cell is based upon quite a different principle than the selenium cell suggested by Bleining³. The photo-electric cell generates a current of electricity, while the selenium cell changes its resistance when exposed to rays of light.

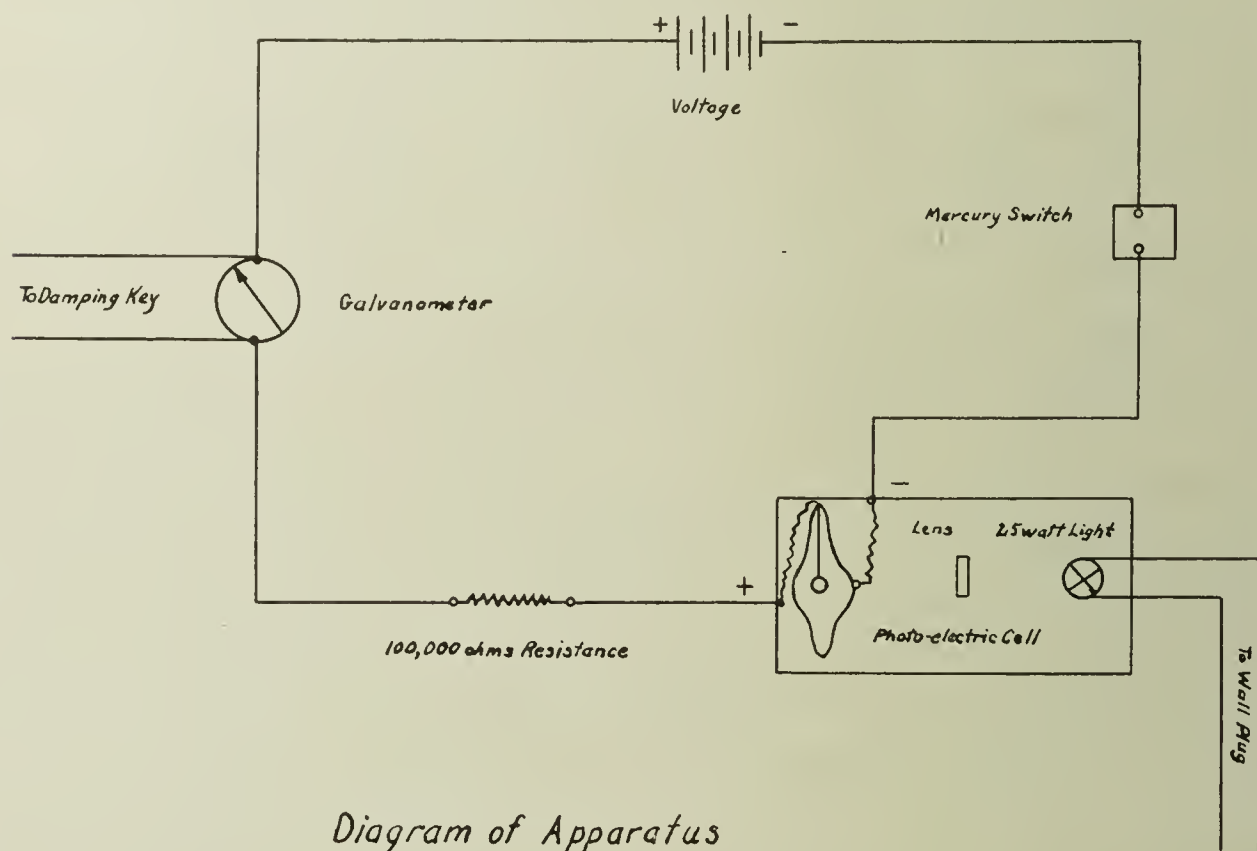
The particular cell which was employed in these experiments was kindly supplied by Dr. Jacob Kunz of the Department of Physics, University of Illinois. The design of the cell is shown in the accompanying sketch. The interior of the cell was coated with a thin film of silver over the en-

¹ Hughes, "Photo-electricity," p. 60.

² *National Research Council Bull.*, "Report on Photo-electricity," by Hughes, p. 106.

³ A. V. Bleining, *Trans. Amer. Ceram. Soc.*, **15**, 543 (1913).

tire surface, with the exception of a small round opening which was left for the admittance of light. Upon this film of silver was deposited a thin film of potassium. This double coating of silver and potassium formed the cathode or negative terminal of the cell. The anode consisted of a hoop of platinum wire, directly in front of and a few centimeters from the cathode. The cell had been completely evacuated, and then a small amount of argon was introduced before it was sealed. This rendered the cell much more sensitive to the effect of light. The set-up of the apparatus is shown in the accompanying diagram. A resistance of 100,000 ohms was connected in series with the cell in order to protect it from a sudden increase in voltage. A galvanometer of the D'Arsenval type was used which had a sensitiveness of 2.711 megs. and a figure of merit of about 10^{-10} . Dry batteries connected in series furnished one hundred and twenty-five volts.



The cathode was connected through a mercury switch to the negative end of the source of the voltage. The positive end of the cell was connected directly to the galvanometer.

The photo-electric cell was placed in a small, light-tight metal box, one side of which had an opening situated opposite to the window of the cell. To this opening on the box was attached a metal frame to which could be secured the small test pieces. A sliding shutter was provided at the opening so that it could be opened or closed at will. The cell was placed in a large wooden box which was painted black on the inside. A 25-watt lamp and a lens were placed opposite the cell so that parallel rays of light would fall upon the test pieces, situated at the opening opposite the window of

the cell. With this apparatus, the work then consisted of the measurement of the amount of current generated by the photo-electric cell when a test piece had been interposed between the source of light and the cell.

The test pieces which were studied consisted of a number of compositions which had been selected with reference to the ordinary range of pottery bodies. In order to insure as nearly uniform thickness as possible, they were first burned to a temperature of 1000° and then ground to the desired thickness. After which, they were refired to the maximum temperature which, in this case, was cone 10. Ten current readings were taken of each piece, and the variations were found to be not greater than $1\frac{1}{2}$ mm. on the galvanometer scale. After the readings the thickness of the test pieces was determined by means of vernier calipers. Measurements were taken from each of the 4 corners and the mean taken as the true thickness of the piece. The test pieces measured 5 cm. x 5 cm., and the thickness of the test pieces varied from 1.2 mm. to 3.0 mm.

Results obtained seem to indicate that the translucency is inversely proportional to the thickness of the specimen. This is in accordance with the experience of others, namely, Ashley and Williams,¹ and also Steger.²

The translucency increases with an increase of the ratio of the feldspar to the clay-silica content. This is especially true in bodies of low silica content. The increase is very rapid in mixtures of low silica (15%) but slight with 35% silica. Only a slight increase is obtained with a clay content above fifty per cent at this cone temperature.

With a constant feldspar content, the translucency increases with an increase in silica, the increase being rapid above 25% feldspar. It was found that the results conformed in general with those which have been reported by Dr. Hecht.³

At present we are engaged in checking the results which have been obtained by this method, and also in extending our field of study of translucency as influenced by body composition and other conditions, namely, color.

The advantage of having such a simple apparatus available for determining translucency in the terms of absolute units is obvious.

It seems worth while also to investigate this method as possibly having a useful application in the study of the color of the transmitted light.

¹ Charles Weelans and H. E. Ashley, *loc. cit.*

² Steger, *Ber. Deut. Keram. Gesell.*, 2 [3], 65 (1921).

³ H. E. Ashley, "Notes on Dr. H. Hecht's Investigation," etc., *Trans. Amer. Ceram. Soc.*, 13, 258 (1911).

THE EFFECT OF SOME SUBSTITUTES FOR TIN OXIDE ON THE OPACITY OF WHITE ENAMELS FOR SHEET STEEL¹

By R. R. DANIELSON AND M. K. FREHAFFER

ABSTRACT

The effect of replacements of tin oxide on opacity of enamels is always of interest. This investigation includes a study of some of the commercial substitutes for tin oxide in a standard frit as well as others which are not in common use. Zirconium oxide and sodium antimonate are apparently the best substitutes and rank very close to tin oxide. Next in order is zirconium silicate, although the purity of the material is of course very important. Opacity does not always increase with increase in amount of opacifier used. Proper calcination of opacifiers is of importance in their effect on opacity.

Visual estimation is not an accurate method for determining the opacity of enamels, although it may be suitable for classifying enamels for such purposes as stove work and table tops. For accurate determination of reflecting value, the method employed by the Colorimetry Section of the Bureau of Standards is described. This involves the use of the spectrophotometer apparatus with illumination box as developed at the Bureau and the calculation of the total diffuse reflection from the spectrophotometric data.

PART I

Opacifying Effect of Tin Oxide and Its Substitutes

Introduction

The subject of the replacement of tin oxide in enamels is always of interest to enamellers. This is due, in part, to the desire to produce enamels of the highest opacity at the lowest cost and in part to the demand for materials which may add some desirable property to the enamel and still not decrease the opacity of the enamels. (The term *opacity* as used by enamellers signifies the power of the enamel to mask the ground coat to which it is applied. As the thickness of the enamel layer is increased, the smaller is the amount of light that reaches the ground coat, and that reaches the observers' eye from the ground coat. A thin layer of enamel of high opacity will be equivalent in this respect to a thick layer of low opacity; but the advantage of using the former is obvious.)

This investigation is concerned only with the comparative effect of tin oxide and some of its substitutes on the opacity of the enamel, and methods for accurately determining opacity, by means of the diffuse reflecting power. Since tin oxide is almost invariably added to sheet steel enamels in the mill during grinding of the frit, this work will deal with the replacement of tin oxide in the mill batch.

Preparation of Enamels

A standard white frit of the following composition was used in this investigation:

¹ By permission of the Director, U. S. Bureau of Standards.

BATCH WEIGHT	
Borax.....	25
Feldspar.	32
Quartz.....	18
Soda ash....	4
Sodium nitrate.....	3
Cryolite.....	12
Antimony oxide.....	2
Fluorspar	4
<hr/>	
100	

The frit was ground in approximately 2.0 lb. batches in a ball mill, with a constant mill addition of 6% of clay, 0.5% of magnesium carbonate and 60% of water. The addition of opacifiers was varied in amounts, in the case of tin oxide being 7%, while the addition of substitutes varied from 7% to 11%.

In Table I is given a list of the enamels designated by their laboratory number and the type and percentage of opacifier added to the frit in the milling.

TABLE I
TYPE AND PERCENTAGE OF OPACIFIER USED IN THE ENAMEL

Laboratory number	Opacifier	Per cent used	Source	Remarks
1	Tin oxide	7	Trade	....
5	Sodium antimonate	7	Trade	....
6	Sodium antimonate	9	Trade	....
7	Sodium antimonate	11	Trade	....
11	Titanium oxide	7	Trade	Impure material
9	Magnesium aluminate	7	Bureau	Calcined at approx. 1200°C
2	Zinc oxide	7	Trade	....
3	Zinc oxide	11	Trade	....
8	Zinc aluminate	7	Bureau	ZnO.Al ₂ O ₃ calcined at approx. 1200°C
16A	Zinc aluminate	9	Bureau	ZnO.Al ₂ O ₃ calcined at 1000°C—2 hours
16B	Zinc aluminate	9	Bureau	ZnO.Al ₂ O ₃ not calcined
16D	Zinc aluminate	9	Bureau	2ZnO.3Al ₂ O ₃ not calcined
13	Commercial substitute	7	Trade	....
15A ¹	Feldspar opacifier	9	Bureau	Calcined at 1000°C
4	Zirconium oxide	7	Trade	....
14	Zirconium oxide	9	Trade	....
10	Zirconium product	7	Trade	Claimed to be zirconium oxide
17	Zirconium product	9	Trade	Claimed to be zirconium oxide
18	Zirconium product	11	Trade	Claimed to be zirconium oxide
12	Zirconium silicate A	7	Trade	} From dealer A
19	Zirconium silicate A	9	Trade	
20	Zirconium silicate A	11	Trade	
25	Zirconium silicate B	7	Trade	} Calcined 1000°C
25A	Zirconium silicate B	7	Trade	
26	Zirconium silicate B	9	Trade	
27	Zirconium silicate B	11	Trade	

¹ Feldspar opacifier: feldspar 51.0, soda ash 12.0, whiting 13.0, fluorspar 7.0, cryolite 9.0, sodium antimonate 8.0; ground in ball mill.

Preparation of Enameled Test Plates

The various enamels were applied by means of an air spray to iron plates which had previously been coated with a ground coat of the following composition:

FRIT		MILL	
Borax.....	28.5	Frit....	100
Feldspar.....	31.2	Clay.....	6
Flint.....	20.0	Borax..	2
Soda ash.....	9.0	Water.....	50
Sodium nitrate.....	4.0		
Fluorspar.....	6.0		
Cobalt oxide.....	0.35		
Manganese oxide.....	0.95		
<hr/>			
100.00			

The size of the test plates was 53 x 35 mm. (approximately 1³/₈ in. x 2 in.) made to conform to the dimensions of the spectrophotometric apparatus. The same plates were also used for classifying the enamels by visual observation.

In order to prevent variations due to thickness of the enamel coating, a number of trials was made for each enamel, and plates having approximately the same weight of enamel were used for the determination of opacity. All enamels were applied in two applications. The weights of enamel on the test plates after firing are included in Table II.

Classification of Opacifiers by Visual Estimate

In order to classify the opacifiers, two methods were used. In the first, the plates which had been coated with the various enamels were carefully examined and placed in the order of opacity by two observers. While there were some minor differences of opinion as to proper classification, column 5 of Table II represents the final classification agreed upon by two observers. In Class A are grouped those compositions giving excellent opacity, such as might be required for reflector enamels. Class B contains those compositions which might be suitable for products in which high opacity or reflecting value is not essential. Class C gives those compositions which might serve as partial substitutes for tin oxide, and Class D, those which are unsatisfactory for white enamels.

Classification of Opacifiers by Reflecting Power

Since it was impossible to differentiate in some cases between enamels having increasing amounts of opacifying agents, it seemed desirable to resort to some more definite method of comparison than is possible in

visual observation. The more satisfactory enamels were, therefore, tested by the Colorimetry Section of the Bureau for spectral reflection values and total reflection. Only the results of these determinations are given in Part I; but a brief description of the scientific method and the spectrophotometric apparatus used for these determinations and also the spectral reflection curves obtained, are given in Part II of this report. This method yields results that are more accurate than has been considered necessary for this type of work, but the need of greater accuracy than is possible from visual observation becomes apparent from the results of this investigation.

Result of Classifications

The following Table II gives, in column 1 the laboratory number of the sample, in column 2 the kind of opacifier used and in column 3 the amount in per cent; in column 4 is the weight of the enamel in grams; in column

TABLE II
CLASSIFICATION OF ENAMELS FOR OPACITY

Lab. no.	Opacifier	Per cent used	Weight in grams of enamel on test plate	Classification as estimated by two observers	Per cent total light reflected
1	Tin oxide	7	1.43	A	69.4
7	Sodium antimonate	11	1.48	A	67.2
4	Zirconium oxide	7	1.39	A	65.8
14	Zirconium oxide	9	1.42	A	65.4
6	Sodium antimonate	9	1.41	B	64.8
5	Sodium antimonate	7	1.44	B	63.0
27	Zirconium silicate—B	11	1.48	B	64.8
25A	Zirconium silicate—B (calcined)	7	1.39	B	60.6
26	Zirconium silicate—B	9	1.48	B	63.0
25	Zirconium silicate—B	7	1.41	B	58.2
13	Commercial substitute	7	1.41	C	55.5
15A	Feldspar opacifier	9	1.34	C	58.2
16B	Zinc aluminate	9	1.35	C	54.5
16A	Zinc aluminate (calcined)	9	1.53	C	55.8
18	Zirconium product	11	..	C	..
8	Zinc aluminate (calcined)	7	1.56	D	56.6
12	Zirconium silicate—A	7	1.38	D	52.2
16D	Zinc aluminate	9	1.31	D	48.5
20	Zirconium silicate—A	11	1.33	D	48.3
2	Zinc oxide	7	..	D	..
3	Zinc oxide	11	..	D	..
9	Magnesium aluminate	7	..	D	..
10	Zirconium product	7	1.38	D	51.0
11	Titanium oxide (impure)	7	..	D	..
17	Zirconium product	9	1.36	D	..

5 there is given the classification of the enamels according to the eye estimate of two observers, and in column 6 is the fraction of sunlight diffusely reflected, the calculation of which is explained in Part II.

Not all of the samples were examined for reflection; hence the table is not complete. A sufficient amount of data has been obtained, however, to bring out some very important facts.

From the above table, it is to be noticed that there are some disagreements between the *estimated* classification in order of opacity and the classification according to the total reflection. Samples 25 and 15A for instance, which according to column 6 belong in the same class, have been assigned to different classes, and the classification of sample No. 8 is not consistent. In Classes B, C, and D, the order of arrangement by visual estimate is not the same as the order of arrangement by total reflection. Two causes contribute to these discrepancies: the presence of hue (blue or yellow) and the presence of glare. The former has the tendency, for the enamels appearing slightly blue, to lower the observer's estimate; the presence of glare or shine on the surface of the enamel tends to raise the estimate.

While the presence of hue is, of course, somewhat of a disadvantage in an enamel intended to be white or without hue, the shine or glare is a decided advantage sometimes, depending on the use to which the enamel is to be put. This is particularly true of enamels for stove parts, table tops and similar ware.

The effect of the treatment of the enamel and of the amount of opacifier used can readily be ascertained by reference to Table III.

TABLE III

Lab. no.	Opacifier	Per cent used	Weight in grams of enamel	Total light reflected	Treatment
1	Tin oxide	7	1.43	69.4	....
7	Sodium antimonate	11	1.48	67.2	....
6	Sodium antimonate	9	1.41	64.8	....
5	Sodium antimonate	7	1.44	63.0	....
27	Zirconium silicate B	11	1.48	64.8	....
26	Zirconium silicate B	9	1.48	63.0	....
25A	Zirconium silicate B	7	1.39	60.6	Calcined at 1000 °C
25	Zirconium silicate B	7	1.41	58.2	....
14	Zirconium oxide	9	1.42	65.4	....
4	Zirconium oxide	7	1.39	65.8	....
12	Zirconium silicate A	7	1.38	52.2	....
20	Zirconium silicate A	11	1.33	48.2	....
8	Zinc aluminate	7	1.56	56.3	Calcined at approx. 1200°C
16A	Zinc aluminate	9	1.53	55.7	Calcined 2 hrs. at 1000°C
16B	Zinc aluminate	9	1.35	54.5	ZnO.Al ₂ O ₃ not calcined
16D	Zinc aluminate	9	1.31	48.5	2ZnO.3Al ₂ O ₃ not calcined

In the case of the first two opacifiers, the opacity is increased as the amount of opacifier is increased. With zirconium silicate A, the opposite seems to be true, and while this may be a property of the material, the reflection value is affected of course by the amount of firing and by the quantity of enamel applied. With zirconium oxide, 7% is apparently as effective as 9%. Since the weight of enamel on the samples varied, no mathematical relation between the total reflection and per cent of opacifier has been attempted.

The data on the zinc aluminate show primarily the effect of treatment and the importance of calcining. The values of total reflection for samples 8 and 16A show apparently that calcination at the higher temperature is equivalent to increasing the per cent of opacifier.

Conclusions

This investigation of substitute opacifiers for tin oxide leads to the following conclusions:

1. Zirconium oxide and sodium antimonate are apparently the best substitutes investigated and are nearly as good as tin oxide itself. Next in order of excellence is the sample of zirconium silicate from dealer B. If either of the first two is used in quantities of about 11% the opacity is strictly comparable with that of 7% of tin oxide. Feldspar opacifier, zinc aluminate and "commercial substitute" in such quantities as used here (7 and 9%) fail to satisfy the requirements for a good opacifier, but may be classed as fair.

2. The opacity does not always increase as the amount of opacifier increases. Apparently an "overloading" is possible which may be deleterious to the opacifier itself.

3. Within certain limits, it is impossible to classify enamels for opacity with accuracy, by merely looking at them. Even the consensus of opinion of several observers does not obviate the possibility of mistakes. If the samples were equally shiny, and of the same color (all blue, all white, or all yellow) such classification would have more value.

4. By determining the spectral reflection curve of an enamel, and from this computing its total reflection for sunlight, an accurate means is provided for determining its relative opacity. This method is free from all errors of personal judgment.

It is to be noted in this connection that primarily the diffuse reflection is involved in these measurements.

5. This investigation is preliminary to further work and it is not to be assumed that the opacifiers included would not give distinctly different results if used in enamels of other compositions.

PART II

Determination of Reflection Values

There are two factors to be considered in the reflection measurements (1) the light diffusely reflected from the enamel and (2) the light diffusely reflected from the ground coat behind the enamel. The ground coat for these enamels was dark bluish gray and its reflecting power was small compared with that of the enamel itself. As the enamel increases in reflecting power, it decreases in transmitting power, which means that the portion of light getting through to the ground coat also decreases; hence the amount reaching the observer's eye from the ground coat becomes correspondingly smaller. Therefore the reflection of light from the *enamel* is a measure of its opacity. Since the ground coat is seen only by virtue of the light that it reflects, this means of measuring the opacity of the enamel, namely by its reflecting power, seems the logical method. There appears to be no rigid definition of the term "opacity" as employed by enamelers. In these experiments, measurements have been made on the light diffusely reflected from the enamel, together with the very small amount reflected from the ground coat.

If sunlight falls on a diffusing surface that is perfectly white, all of this light will be reflected by the surface—that is the reflection will be 100 per cent. Strictly speaking, this is what is meant by the term "white." Since no substances are known with a reflection equal to 100 per cent, it has become customary to speak of substances with a high reflecting power as white, although in fact they are only "nearly white" or gray. The word has been used in the less technical sense throughout this paper.

This investigation was undertaken originally to examine the enamels from the standpoint of selectivity of color. There are very few so-called "white" materials that do not show some predominating hue—yellow, green, etc. It was thought that a study of these characteristic hues might throw some light on the efficiency of the different opacifiers. The results on total reflection, already recorded in Part I, could have been obtained much more easily with a simple photometer or reflectometer.

Spectrophotometric Apparatus

The *reflection* data were obtained with a König-Martens spectrophotometer, used in connection with an illumination box designed at the Bureau of Standards. The apparatus has been described fully elsewhere¹ and these descriptions are available for those interested in the details of the method. The enamel under test and the magnesium carbonate are placed side by side in a block at the back of the illumination chamber. The radiation

¹ *Ann. der Phys.*, 4 [12], 984 (1903); Bureau of Standards, *Sci. Papers*, 440, 126 (1922).

from ten tungsten lamps falls on this block and on the walls of the chamber. The light diffusely reflected from the walls of the chamber also falls on the two surfaces, which in turn diffusely reflect it. From most of the enamel samples there is also considerable specular reflection, due to the glaze of the surfaces, but this constitutes only a small percentage of the light reflected to the measuring instrument. It does however affect the appearance of the field and slightly decreases the accuracy of setting.

The spectrophotometer is sighted upon the two surfaces in a direction normal to them through two apertures in the illumination box, so that each half of the photometric field is illuminated respectively by light from the enamel and the magnesium carbonate. The photometric setting consists in making these two halves equal in brightness. Sample and standard are then interchanged in position and the two halves of the field again brought to equality of brightness. Such settings are made at different wave lengths throughout the visible spectrum. The reflection of the sample relative to the magnesium carbonate under the above conditions of illumination and observation, is computed for each of these wave lengths. From the data thus obtained, the reflection curve for the sample is mapped out (Figs. 1 and 2). Since the absolute values for magnesium carbonate are known to be very high (in the neighborhood of 98%), the values given for the enamels are not far from their absolute values.

In order to measure the total light reflected, the values of the sun's luminosity at the different wave lengths are used. This luminosity involves both the spectral energy distribution in sunlight and the sensibility of the eye to light of different wave lengths.¹ The values of the sun's luminosity are multiplied by the reflection values of the sample, wave length by wave length, and from these data the luminosity curve of the sample can then be plotted. These curves have not been reproduced in this report. The area under this curve is measured by a planimeter. The ratio between this area and that of the sun's luminosity curve gives in per cent, for purposes of comparison, the total amount of sunlight reflected.

Results

The results for the samples examined are shown in the form of graphs, Figs. 1 and 2, in which the per cent reflection has been plotted vertically and the wave length horizontally. The points obtained from the spectrophotometer readings are connected by a smooth curve. The per cent of error in these determinations varies by approximately 1 to 2% of the reflection value, depending upon the wave length and upon the condition

¹ The values for the energy of average noon sunlight at Washington, D. C., are Abbot's data as adopted by Priest, see *Phys. Rev.*, 2 [11], 502, Fig. 1; the values of visibility of radiant energy are those adopted by Priest, see Bureau of Standards, *Sci. Papers*, 417, 236, Fig. 2.

REFLECTION OF WHITE ENAMELS

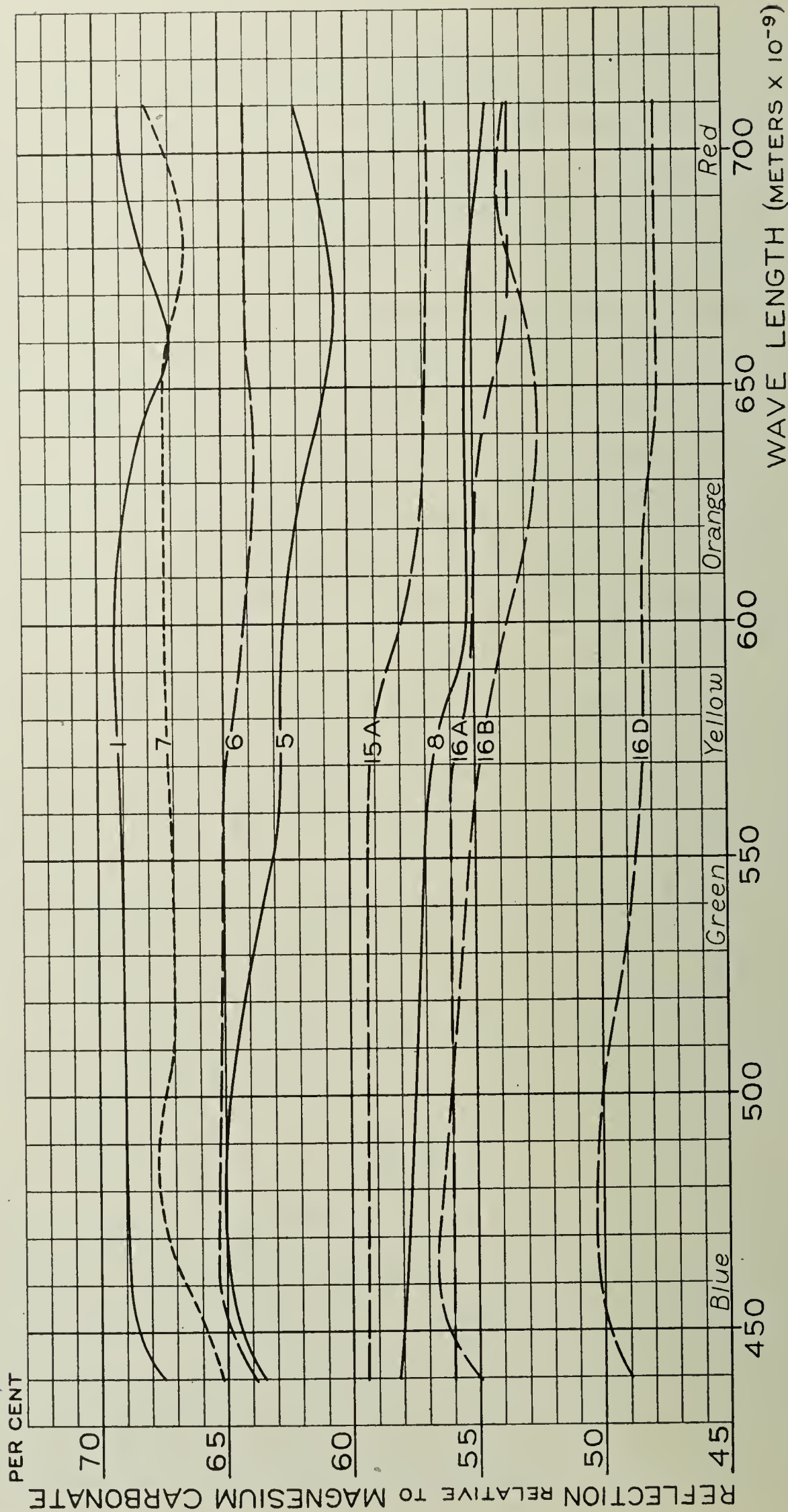


FIG. 1.—Opacifiers for enamels.

No. 1—Tin oxide 7%

No. 7—Sodium antimonate 11%

No. 15A—Feldspar calcined 9%

No. 16A—Zinc aluminate calcined 9%

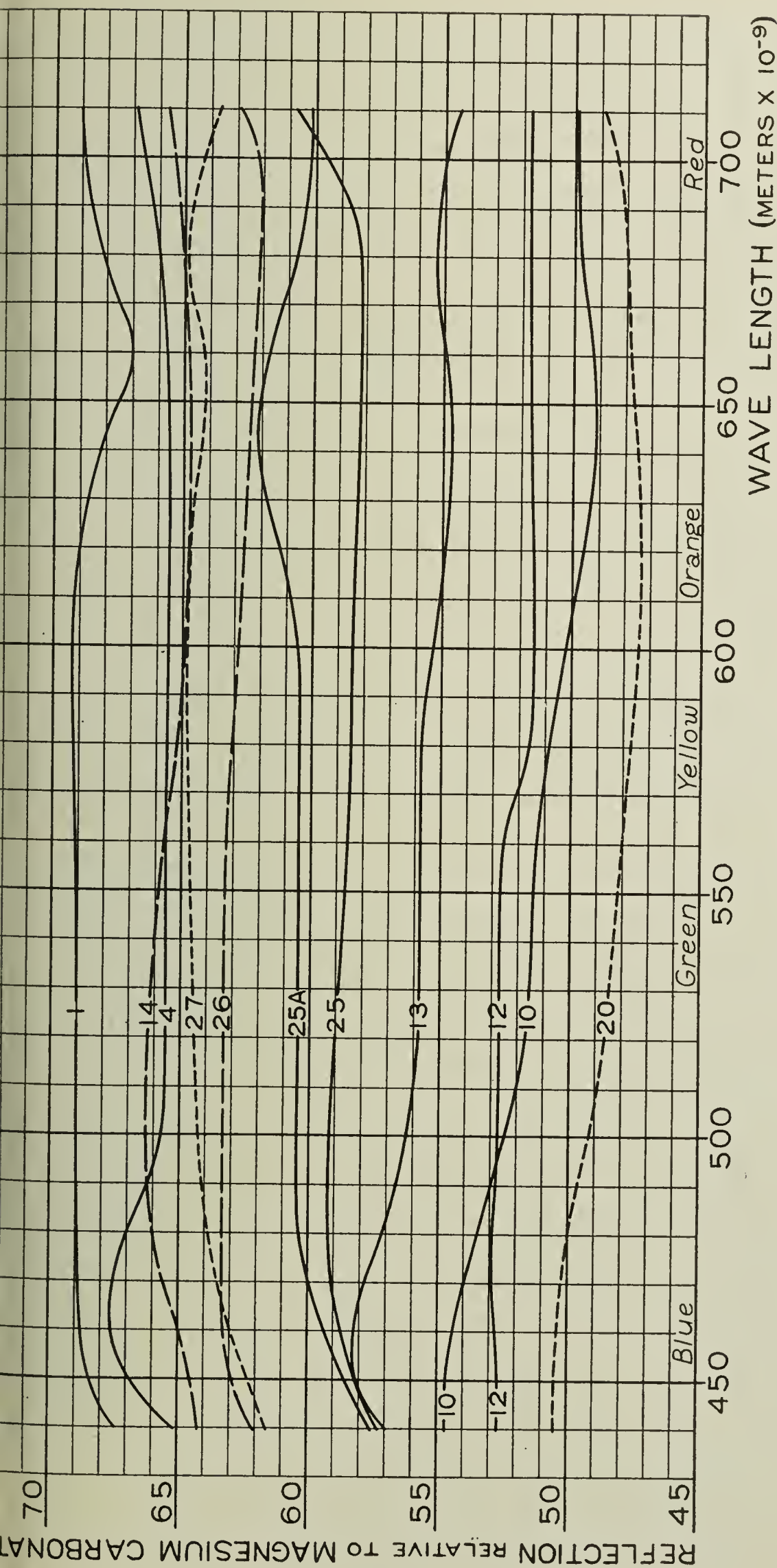


FIG. 2.—Opacifiers for enamels.

- | | |
|---------------------------------|--|
| No. 1—Tin oxide 7% | No. 26—Zirconium silicate B 9% |
| No. 4—Zirconium oxide 7% | No. 25—Zirconium silicate B 7% |
| No. 14—Zirconium oxide 9% | No. 25A—Zirconium silicate B calcined 7% |
| No. 10—Zirconium product 7% | No. 12—Zirconium silicate A 7% |
| No. 13—Commercial substitute 7% | No. 20—Zirconium silicate A 11% |
| | No. 27—Zirconium silicate B 11% |

of the surface under test. Some of the samples, notably numbers 16A, 20, and 10 had rather poor, non-uniform surfaces and sample 13 had marked defects. The values of reflection given, therefore, cannot always be considered as representative of the sample as a whole, as only a part of it (an area a little greater than 1 sq. inch) is concerned in the measurements.

The spectral reflection of a perfect white or gray material would be represented by a horizontal straight line. Since the specimens examined showed comparatively little selectivity, the use of the terms "white" and "gray" as applied to them is justifiable. Some of the enamels were decidedly gray in appearance and of too low reflection to serve as white enamels. It can readily be seen, however, from the curves that a number of these enamel specimens are slightly selective in color, that is they appear somewhat blue or yellow. This is also apparent to the eye in observing the specimens in sunlight. But from the standpoint of opacity, this small selectivity affords very little information for the following reason: Enamels of the same composition, differing only in amount of opacifier used, or in the calcining temperature, do not always appear the same hue. In Fig. 2, this is particularly noticeable in the zirconium silicate group, No. 27 and 25A are slightly yellowish, No. 26 and 25 are slightly bluish. The yellow hue of No. 25A cannot be with any surety ascribed to calcining, as No. 15A and No. 16A of Fig. 1 do not show a similar effect. Other samples of more pronounced hue must be examined before these points can be settled.

The enamels arrange themselves in order of opacity according to the distance of their curves above the horizontal axis. This furnishes a method of comparing the enamels with each other, and of analyzing the effect on the reflection of the different opacifying materials used. It is readily seen from Fig. 2, for example, that the reflection values for sample No. 1 (tin oxide opacifier) are about 21% better than the reflection values for sample No. 20 (impure zirconium silicate opacifier).

The results on the total reflection of the samples have already been given in Table II. While similar results could be obtained more readily with a reflectometer, the analysis of the spectral reflection could not be determined with this instrument. The need of standard apparatus for making accurate measurements on such materials is again emphasized by the results of this investigation.

THE REVERSIBLE THERMAL EXPANSION OF REFRACTORY MATERIALS

By H. S. HOULDSWORTH AND J. W. COBB

ABSTRACT

The reversible thermal expansion from 15–1000°C was measured for kaolin, siliceous and aluminous fire clays, quartzite, alumina, magnesia, and carborundum, after preliminary burnings at cones 06, 9, 14 and 20, and as well as for English commercial silica bricks before and after use in a coke oven and the roof of a steel furnace. Kaolin and kaolinitic fire clay after calcination have a regular reversible thermal expansion which does not vary much with the temperature of calcination. Siliceous fire clays, after calcination at cone 06 (980°C) or cone 9 (1280°C) display irregularities (departures from uniformity) in their expansion. Between 500° and 600°C they show a large expansion due to contained quartz and on cooling the contraction in that region is larger than the corresponding expansion. Moreover, the expansion between 100° and 250°C after being fired to cone 9 (1280°C) exceeds the average. After calcination at higher temperatures, cone 14 (1410°C) or cone 20 (1530°C), these materials gradually lose these peculiarities until on incipient vitrification a linear expansion similar to that of kaolin is attained. This change is due to the destruction of quartz by its interaction with the clay material and fluxes; it takes place most easily in a fine-grained, rather friable clay such as ball clay. The previous thermal treatment necessary for a particular clay in order to obtain regular expansion in use can only be determined by trial. It can be stated with confidence that in such a piece of apparatus as a glass pot or crucible, a distinct gain will result from maintenance at a high temperature for some time before use, but that the red heat of an ordinary pot arch is useless for the purpose. An increase in the porosity of a fire clay was accompanied by a corresponding decrease in expansion between 15° and 1000°C until a porosity of 50% was attained. Further increase in porosity produced very little change in the expansion. No irregularities in expansion were shown by magnesia brick, carborundum, or alumina bonded with 10% of ball clay. Welsh quartzite with lime bond, either unfired or after burning at cone 06, had a large expansion to 550°C and a much larger expansion from 550–600°C due to the inversion of α to β quartz while from 600–1000°C a slight contraction took place. Firing to cone 06 converted part of the quartz into cristobalite, thus increasing the expansion from 200–550°C. This conversion was considerably increased on burning for two hours at cone 14, which greatly reduced the expansion from 550–600°C with a corresponding increase of that from 200–250°C. The conversion of the quartz into cristobalite was completed by a further heating for two hours at cone 20. Determinations of refractive indices and specific gravities confirmed these results. Flint inverted to cristobalite with greater ease than quartz. Commercial silica brick consisted chiefly of cristobalite and unconverted quartz and showed a large expansion up to 300°C, followed by a considerably smaller but regular expansion to 550°C. From 550° to 600°C the rate of expansion was considerably increased, but above 600°C the change in dimensions was small. The innermost exposed layer of a silica brick after use in a coke oven was an impure glass with a steady expansion, but only half as large as that of the layers of brick behind, which was made for shelling away. A silica brick after use in a steel furnace was divided into four layers. The layer exposed to the furnace heat was practically all cristobalite and silicates, the next layer the same, the third layer showed some α to β quartz expansion as well as the α to β cristobalite expansion, while the fourth (outermost) layer exposed to air was similar to the brick before use. In these bricks exposure to high temperature had evidently completed the change from quartz to cristobalite which had been largely effected in the kiln during manufacture. Little or no tridymite had formed.

The reversible thermal expansion from 15–1000°C of the commercial silica brick examined was 1.1 to 1.3%, about double that of fire clay brick.

Introduction

The following paper brings together the results obtained in studying in our laboratory in Leeds the reversible thermal expansion of a number of refractory materials including pure clays, fire clays, bauxites, alumina, carborundum, magnesia and silica; it deals also with the transformation of silica as occurring in various forms of silica and silica refractories. More detail than it was possible to give here can be found in the following papers where, too, fuller reference is made to the work of others.¹

The change in volume which occurs on heating is one of the most important physical properties of refractory materials and may at times be decisive in the attainment of success in their application to large scale practice.

The actual change in volume may be due to two factors, the one permanent and usually spoken of as the “after-contraction” or “after-expansion,” the other temporary and solely dependent on the temperature and therefore reversible. The work described in this paper was undertaken in order to obtain data of the reversible thermal expansion of refractory materials, a subject which hitherto had not received the attention it deserved.

Apparatus

The apparatus used was similar to that described by Boeck.² A silica glass (vitresil) tube A (see Fig. 1) was heated in a nichrome-wound electrical furnace, the end of the tube projecting from the furnace being at

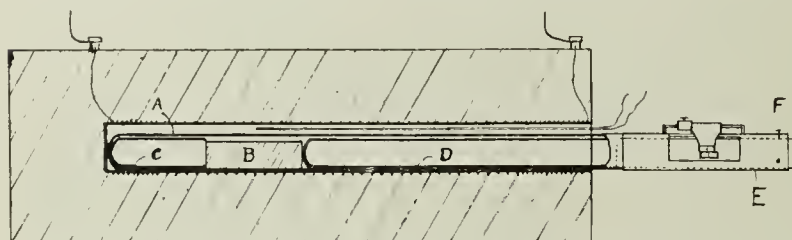


FIG. 1.

attached to a brass tube E. The test piece in the form of a rod 20 cms. long and 2.5 cms. thick was placed inside this silica tube together with silica glass distancepieces C and D of such lengths that the specimen oc-

cupied the zone of uniform temperature of the furnace. The distance piece D was cemented to another brass tube F, which could slide between guiding screws within the outer brass tube E. The inner and outer brass tube each carried a small glass plate marked with a fine scratch. The relative movement of the scratches was observed with a microscope fitted with micrometer eyepiece and gave the expansion of the test piece relative to

¹ For a fuller discussion see *Trans. Soc. Glass Tech.*, **3**, 201–22 (1919); *ibid.*, **5**, 16–4 (1921); *Trans. Eng. Ceram. Soc.*, **21**, 227–76 (1921–22).

² *Trans. Amer. Ceram. Soc.*, **14**, 470 (1912).

silica glass, the expansion of which was very small and was accurately known between 15° and 1000°C.¹ One division of the scale of the micrometer eyepiece corresponded with 1114×10^{-6} mm. Temperatures were observed by means of a thermocouple attached to the outer silica glass tube and having its junction about the middle of the specimen.

Results Obtained

(a) **Kaolin and Highly Aluminous Clays.**—The expansion curves obtained for kaolin and a highly aluminous (Ayrshire bauxitic) clay (see Fig. 2) were very similar.

Test-pieces fired to cone 06 showed a regular expansion with rise of temperature. The total expansion from 15–1000°C was increased after burning at cone 9, the rate of expansion from 15–200°C being now greater than in any other part of the temperature range. The expansion was slightly decreased by giving the specimen a preliminary firing for two hours at cone 14, the rate of expansion from 15–200°C being still greater than from 200–1000°C. After firing for two hours in a laboratory furnace at 1520–1555°C, resulting in a very close-grained fracture and great reduction in porosity, it was found that the greater rate of expansion from 15–200°C had been removed

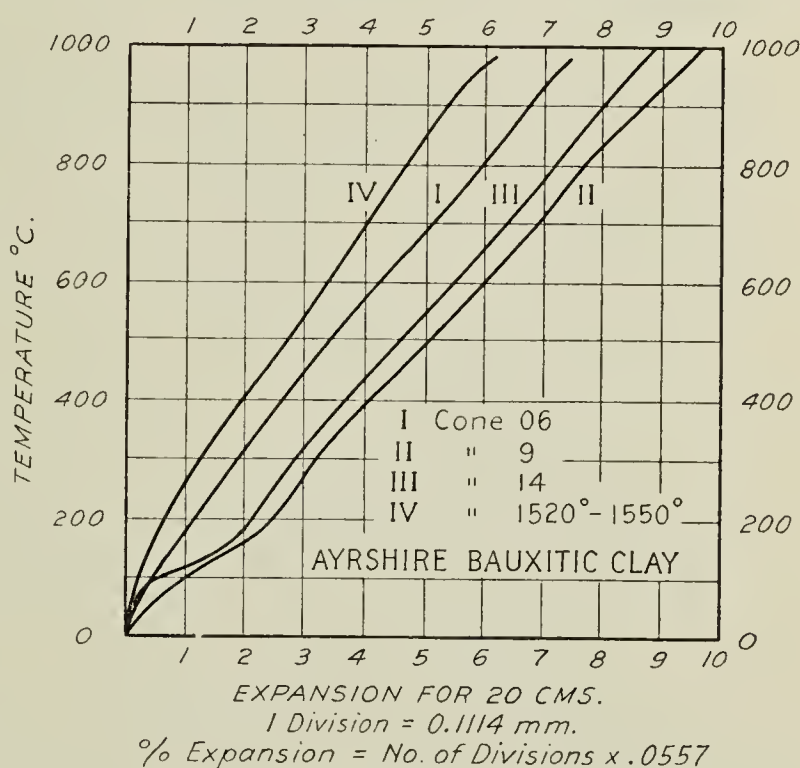


FIG. 2.

and that the expansion from 15–1000°C had been considerably reduced. Free quartz was not detected in the expansion of any of these test-pieces.

(b) **Fire Clays Containing Free Silica.**—Farnley (Yorkshire) fire clay (see Fig. 3) was mixed by hand to a fairly soft plastic condition, molded, dried, and burned in a works kiln to cone 06 in forty-eight hours, and to cone 9 in seventy-two hours. The test-piece fired at cone 06 expanded regularly to 550°C but the rate of expansion was considerably increased from 550° to 600°C, due to the volume change associated with the inversion of the free α quartz of the clay to β quartz. The test-piece then expanded regularly to 900°C the rate of expansion from 600° to 900°C being less than from air temperature to 550°C.

After burning at cone 9 the expansion of the clay between 100° and 250°C was about double that given by the cone 06 test-piece. The expansion

¹ Kaye, *Phil. Mag.*, 6 [20], 718 (1910).

from 500–600°C was slightly less than for the latter specimen but the total expansion from 15–1000°C was considerably greater. On examining the cone 9 sample after heating for two hours in a laboratory furnace at cone 14 (1400°C), resulting in a very slight vitrification and fall of porosity it was found that the expansion between 100° and 250°, 500–600°C, and 15–1000°C were all a little less than before this treatment, but the total expansion to 900°C was still greater than that found for the test-piece fired to cone 06. In each case the contraction on cooling from 600–500°C was greater than the expansion on heating from 500–600°C. This difference between the heating and cooling curves was found for all the clays examined which contained free quartz.

The test-piece was next fired in a laboratory furnace for two hours at 1520–1555°C. On examining the test-piece, which had vitrified to a sugary

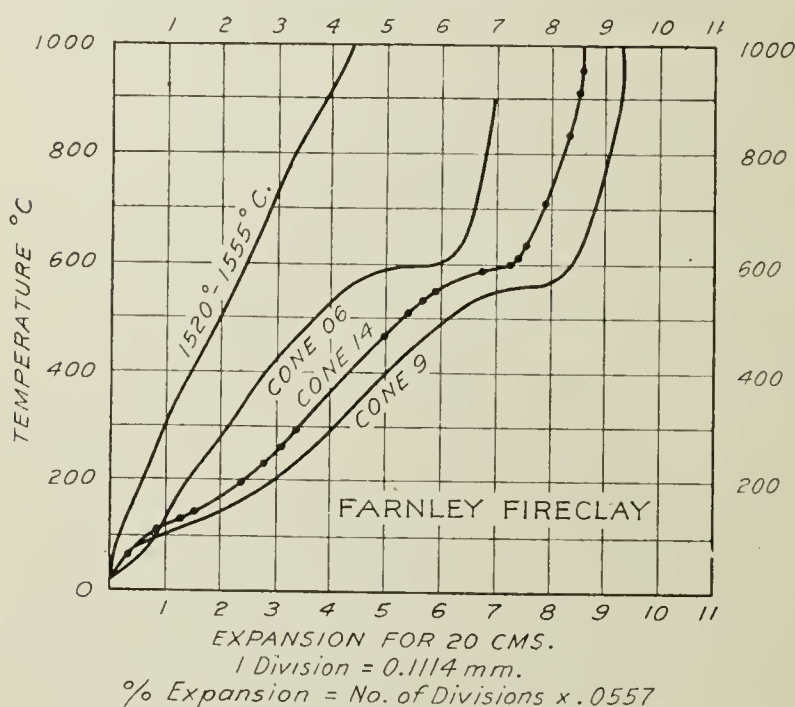


FIG. 3.

fracture with a great fall in porosity, a marked change in the temperature-expansion curve was found. The rapid expansions associated with the ranges 100–250°, and 500–600°C had disappeared and the expansion was found to be regular. The small coefficient of expansion which the specimen showed was worthy of note. No free quartz could be detected. Similar results were obtained with the other siliceous clays [Stourbridge, Scottish (Atlas), and Halifax (both before and after experimental electric osmosis)] examined, the heat treatment necessary to remove the α to β quartz expansion being considerably lower for a Dorset ball clay vitrifying at a relatively low temperature. The changes are associated in some way with the process of vitrification and mark, presumably, the disappearance of the quartz by interaction with the clay substance. Microscopic examination of a section of the clay after burning at 1550°C showed the specimen to be a glass with small bunches of radial crystals, probably sillimanite distributed through it. The lowering of the coefficient of expansion noted with fire clays when vitrification had commenced and the quartz effect had been destroyed has its parallel in glazes and glasses. The proportion of unvitrified quartzose silica induces considerable and irregular increases in expansion, but as soon as the silica is brought into complete solution or combination, as, for example, in a clear glass or glaze, the result is a reduction in the coefficient of expansion.

(c) **Alumina, Magnesia Brick, Carborundum** (see Fig. 4).—The expansion-temperature relationship for alumina (fine-calcined alumina as prepared commercially from bauxite for the manufacture of aluminium and bonded with 10% of ball clay), magnesia brick, and carborundum were all nearly linear and only slightly modified by the variations in preliminary heat treatment. The expansion of carborundum was small and that of magnesia large, while the expansion of alumina was intermediate between those of carborundum and magnesia.

(d) **Effect of Porosity on Expansion of Fire Clay**.—Since the expansion of a test-piece must be determined by the degree of effective continuity resulting from the juxtaposition of its constituent particles, it may be expected to be influenced by breaches of that continuity brought about by pores

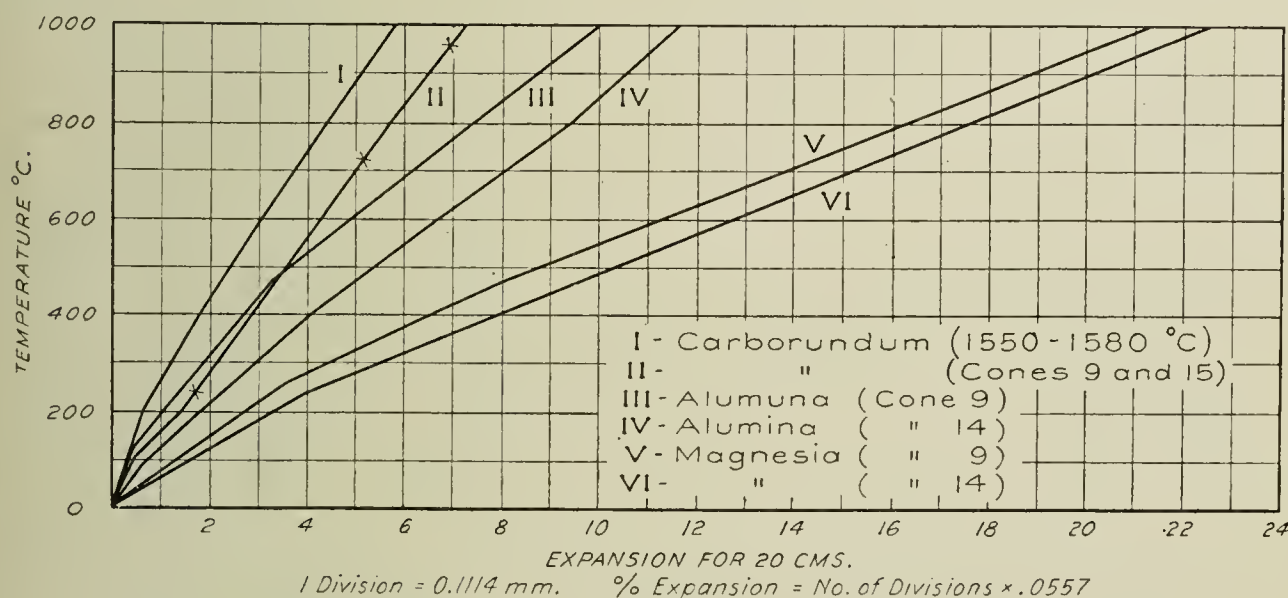


FIG. 4.

in the material. The size and shape of the pores are no doubt of importance, and to give definiteness to the tests we produced differences in porosity by the introduction of combustible grains of one known size.

Farnley fire clay was ground and sieved through a standard 20-mesh (I.M.M.) sieve, and test-pieces were prepared from the clay after mixing with rape seed as uniformly as possible. The specimens were fired in a works kiln, so as to burn out the seed and leave pores. The average volume of the rape seeds used was 0.00287 cc., corresponding with a diameter of 0.176 cm.

The porosity¹ of the test-piece made from the clay without the addition of rape seed was 28.7% and its coefficients of expansion were as follows:

15-500°	769×10^{-8}	600-1000°	183×10^{-8}
500-600°	1275×10^{-8}	15-1000°	583×10^{-8}

A test-piece prepared as described above, and having a porosity of 44.6%,

¹ That is, percentage volume occupied by open pores.

showed, as was anticipated, a smaller expansion (see Fig. 5) its coefficient of expansion for the various ranges being:

15–500°	602×10^{-8}	600–1000°	281×10^{-8}
500–600°	1053×10^{-8}	15–1000°	517×10^{-8}

A specimen with a porosity of 50.2% had a still smaller expansion giving values of:

15–500°	550×10^{-8}	600–1000°	295×10^{-8}
500–600°	997×10^{-8}	15–1000°	491×10^{-8}

A further increase in porosity did not produce any measurable change in expansion, a test-piece of porosity 58.0%, giving results practically identical with those obtained for the

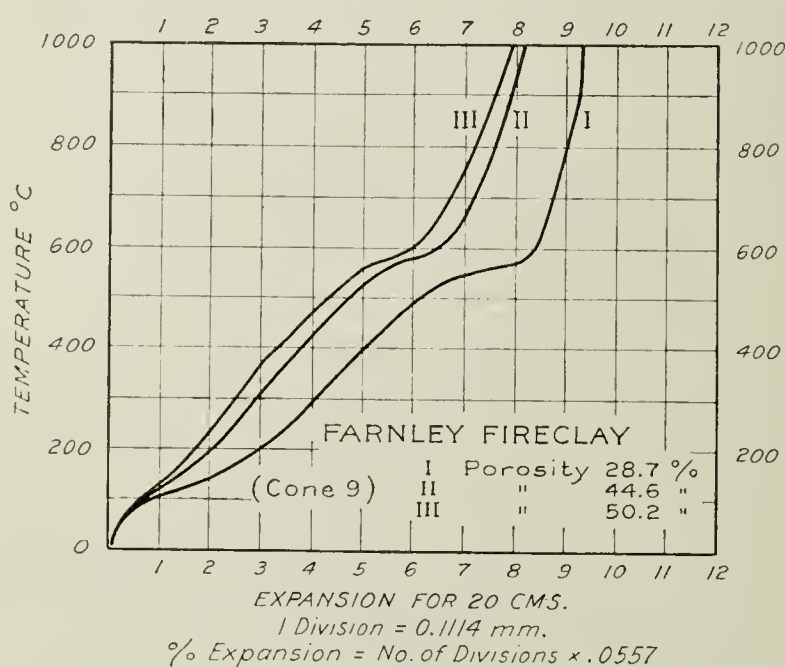


FIG. 5.

specimen with a porosity of 50.2%. The results are shown graphically in Fig. 5.

It thus appears that up to a certain point (namely, a porosity of 50%) increased porosity resulted in a decreased expansion, although in one range (600–1000°C) there was actually a slight increase in expansion with increasing porosity.

(e) Quartzite (see Fig. 6).—A

Welsh (Bwlchgwyn) quartzite

was ground and sieved through a standard (I.M.M.) 20-mesh sieve, 3% of plaster added as slip and dried. A test-piece was examined in the expansion apparatus without being submitted to any preliminary burning. It had a large coefficient of expansion from 15–600°C owing to the inversion of α to β quartz. From 500–750°C practically no further change in dimensions was detected and the specimen contracted slightly from 750–1000°C. A test-piece which had been fired in a works kiln to cone 06 gave a similar expansion-temperature graph, but the expansion between 550° and 600°C was less than that for the unfired sample. Determination of density and refractive indices showed, however, that this result could not be attributed to any conversion of the quartz into other modification of silica. The greater expansion of the unfired specimen was due to the permanent expansion of the test-piece on firing, which was superimposed on the ordinary reversible thermal expansion, the difference in the expansion of the cone 06 and unfired specimens being approximately the same as the permanent expansion shown by the latter on heating to 1000°C. This permanent expansion is due not to the conversion of quartz into the

lower density forms of silica, but to an increase in the porosity of the sample, a result which as studied in more detail for Meanwood ganister which had a larger permanent expansion (about 0.7%) on first heating to 1000°C. It was found that practically no change in specific gravity or refractive index had taken place but the porosity had increased from 14.4% to 17.0%.

The temperature expansion curve for the quartzite burned to cone 9 (Fig. 6, curve C) in a works kiln was very different. The test-piece expanded steadily to 150°C but from this temperature to 250°C a much greater rate of expansion was noted. From 250° to 550°C the rate of ex-

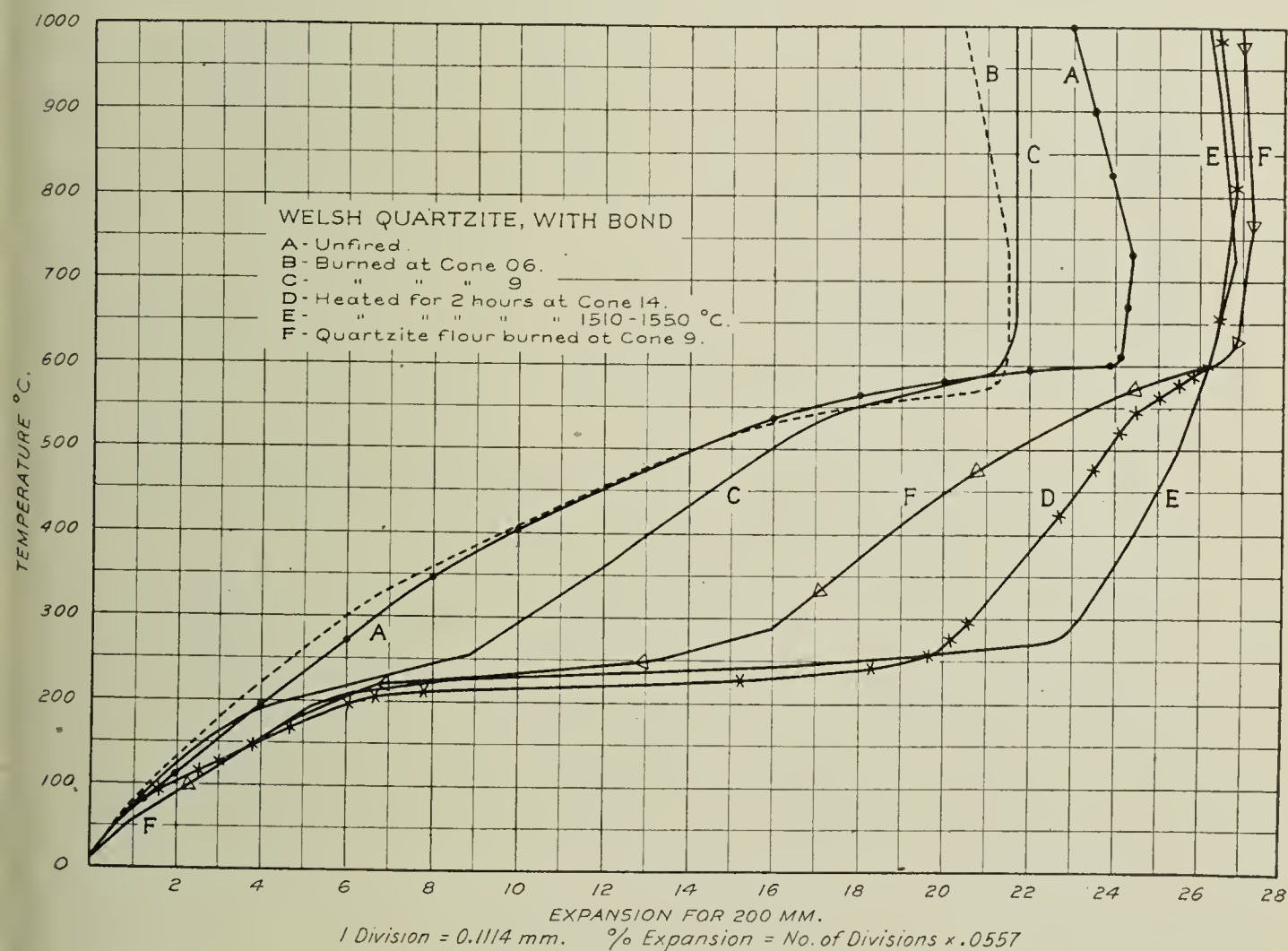


FIG. 6.

pansion was again smaller, but a large increase in the rate was observed from 550° to 600°C. From 600° to 1000°C there was practically no increase in dimensions. The cooling curve nearly coincided with the heating curve so that the abrupt changes in length at 150° to 250°C and 550° to 600°C were reversible and were evidently due to the inversion of α to β cristobalite, and of α to β quartz, respectively. The actual expansion to 1000°C was the same as for the test-piece fired to cone 06. The specific gravity of the quartzite had decreased to 2.58, while the index of refraction of all the material was greater than 1.481 and of nearly all greater than 1.503, indicating quartz mixed with a small amount of cristobalite, results

which were in agreement with the changed character of the expansion curve.

The specimen was next fired in the laboratory for two hours at cone 14, which produced a permanent expansion of 2.6%. It was again examined in the expansion apparatus (see Fig. 6, curve D). The length increased regularly up to 200°C but from 200° to 250°C an extremely rapid expansion occurred amounting to 0.75% of the original length of the test-piece. From 250° to 550°C the sample expanded regularly, but from 550° to 600°C there was the usual rapid rate of expansion always observed with quartz. The quartz expansion, was, however, only about one-third of that noted after burning at cone 9. A slight expansion took place from 600° to 800°C after which the test-piece contracted slightly to 1000°C. The cooling curve was almost identical with the heating curve so that the rapid expansions noted between 550° and 600°C and 200° and 250°C were reversible and must be associated with the inversion of α to β quartz and α to β cristobalite, respectively. This result was supported by a determination of the specific gravity which was 2.35, a value which would agree with a large amount of cristobalite (specific gravity 2.33) associated with some quartz (specific gravity 2.65). A microscopic examination of the powdered specimen showed it to consist of a mixture of quartz and cristobalite. No tridymite could be detected, all the material having an index of refraction greater than 1.481.

The test-piece was next fired for two hours in a laboratory furnace at 1510° to 1520°C (cone 20) and its expansion again determined. The expansion-temperature curve (Fig. 6, curve E) was practically along the one obtained for the cone 14 test-piece up to 200°C but from this point to 250°C there was a somewhat greater expansion. From 250° to 550°C the expansion was small but regular, while from 550° to 750°C the rate of expansion was smaller. No rapid expansion between 550° and 600°C could be detected, indicating the absence of quartz from the specimen. From 750° to 1000°C a slight contraction was noted. The rapid expansion between 200° and 250°C was again reversible and was due to the α to β cristobalite inversion. It would seem that the whole of the quartz had been converted into cristobalite, a result which was confirmed by the specific gravity which had become 2.33. The refractive index of all save one or two grains was between 1.481 and 1.503 so that the microscopic examination also showed that the quartzite had been converted completely into cristobalite, the few grains with index of refraction greater than 1.503 probably being silicates.

Summarizing, the quartzite on burning to cone 06 showed only a small permanent expansion and was still unconverted quartz. Firing to cone 9 converted part of the quartz into cristobalite, the conversion being considerably increased on burning for two hours at cone 14, and completed

after a further heating at cone 20 for two hours. No evidence of the conversion of the quartzite into tridymite was observed. The conversion of the quartz into cristobalite brought about a larger expansion from 15° to 1000°C after burning at cone 14 or cone 20 than after firing to cone 06 or cone 9. By far the greater part of the expansion, however, had been brought into the range 15° to 300°C the increase in length being small between 300 and 1000°C. This result bears distinctly on furnace practice. With bricks in which the quartz had been converted into cristobalite by hard firing, no strain and danger of fracture would result from fluctuations of temperature between 1000° and 300°C after the temperature of 300°C had been once attained, whereas with lighter burned bricks containing quartz strain would result whenever the temperature fell below 600°C. The large and rapid expansion up to 300°C for the material fired to cone 14 and upwards emphasized, however, the necessity for slow and careful heating in the initial period of heating if expansion strains were to be avoided.

Flint behaved very similarly but was converted into cristobalite with greater ease, no quartz remaining after the test-piece had been heated at cone 13-14 for two hours. A local (Meanwood) ganister inverted much more slowly

(f) **Commercial Silica Brick.**—So far only specially prepared specimens had been used. Experiments were next conducted on commercial silica brick, two of them being made from the Welsh quartzite we had studied by kilning at about cone 16. Silica brick of the same manufacture were also examined after use in coke ovens and steel furnaces so that the effect of long industrial heating could be studied.

Sample A (see Fig. 7, curve A).—The first brick examined was one made from Welsh quartzite (Bwlchgwyn). A test-piece was cut from the actual brick and examined. A very large coefficient of expansion was observed from 15° to 250°C followed by a considerably smaller but regular expansion to 550°C. From 550° to 600°C the rate of expansion was considerably increased. A small coefficient of expansion was found between 600° and 750°C, and from this temperature to 1000°C there was a slight contraction. The large expansion up to 250°C could be associated with the transformations of tridymite and cristobalite, while the increased rate of expansion from 550° to 600°C would correspond with the inversion of α -quartz into β -quartz. It was apparent that the burning of the brick in the kiln had caused the transformation of a large part of the quartz into other forms of silica. The large expansion caused by the low temperature inversion of the cristobalite present in the silica brick caused the expansion of the brick from 15° to 1000°C to be more than double that for a fire-clay brick. It would demand slow and careful heating with no rigid ties when the structure was first heated, and would be a source of danger from

rate of expansion from 250° to 550°C. At this stage a remarkable and unexpected difference was observed, for no discontinuity between 550° and 600°C such as had always been noted in the case of free quartz was detected. Instead, the brick expanded fairly regularly to 900°C after which there was no further expansion to 1000°C. Apparently all the quartz had been converted into other forms of silica. The large expansion from 15° to 25°C would be explained by the presence of tridymite and cristobalite. The specific gravity of the brick was 2.35. Determinations of

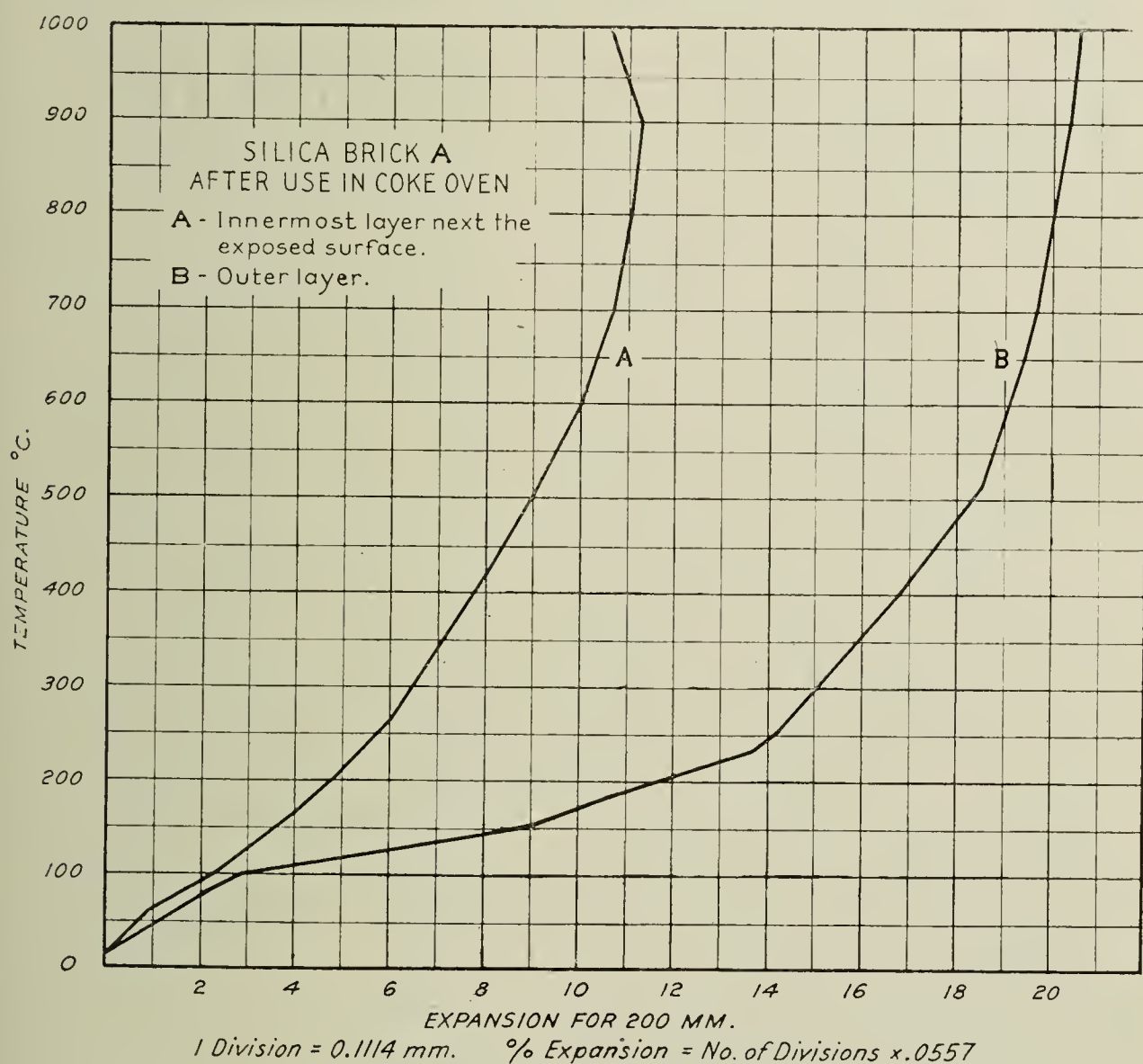


FIG. 8.

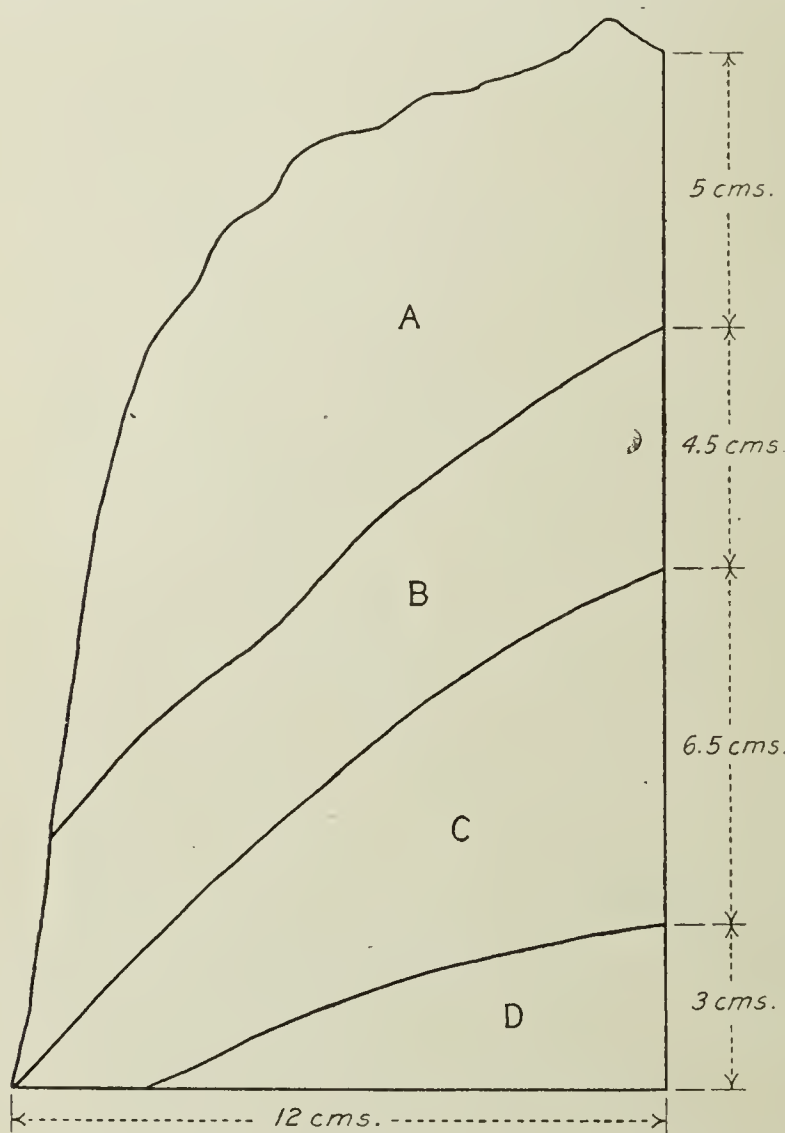
the refractive indices of the particles of the powdered brick showed it to consist chiefly of cristobalite mixed with a very small amount of tridymite and some material of refractive index greater than 1.503 probably silicates. No quartz could be detected in a microsection cut from this brick.

Silica Brick after Use in a Coke Oven

A silica brick of the same manufacture (see Fig. 8) as sample A was examined after fourteen months' service at a probable maximum temperature of 1450°C, in a coke oven. On dividing the brick four fairly distinct layers were noted. The innermost layer next the exposed face was

grayish black with large white grains clearly distinguishable, and a brownish black outer crust. This layer was about six-tenths of an inch thick, and was followed by about a one-inch layer of light brown material. The next layer was dark brown and was about one and one-half inches thick, and was succeeded by a light brown layer about one inch thick. This last part looked very much like unaltered brick.

The expansion curve obtained for the material from the innermost grayish black layer showed none of the breaks which we were accustomed



SECTION OF BRICK FROM ROOF OF STEEL FURNACE

- A- Innermost layer next the face exposed in the furnace. Grey to slaty black; honeycombed; vitrified. White grains not seen.
- B- Second layer. Black to dark grey with a few large white grains. Semi-vitrified and honey-combed.
- C- Third layer. Light grey with large white grains and specks of yellow.
- D- Fourth layer. Reddish in color.

FIG. 9.

to get from material containing quartz, cristobalite, or tridymite. The coefficient of expansion diminished slowly and continuously as the temperature rose. It was such as might be expected from a contaminated quartz glass and the total expansion from 15–1000°C was only one-half that of the layers behind it. The composition of the material in the layer can be expressed empirically by the formula $RO; .4 Al_2O_3; 14.3 SiO_2$. The outer crust which was obviously partially fused was, no doubt, richer in basic material including ferric oxide. The expansion temperature curves obtained for the other three portions of the brick were practically identical, and the actual expansion from 15° to 1000°C was in each case almost the same as that obtained for the unused silica brick. The character of the curves, however, was somewhat different from that given by the unused brick.

There was a rather more rapid expansion from 15° to 150°C and practically no sudden expansion at 550° to 600°C. Above 600°C also the specimens continued to expand whereas the unused silica brick contracted slightly above 700°C. It would seem that the long heating to which the brick had been subjected had completely transformed the original quartz of the brick. The refractive index of the material of these

layers was nearly all less than 1.503 and nearly all greater than 1.481 so that microscopic examination showed them to be cristobalite associated with a little tridymite and quartz or silicates of higher refractive index. The difference in the expansion between the outer darker portions and the remainder of the brick demonstrated one cause of wearing of the brick in use. The expansion from 15° to 1000°C of this darker layer was only about one-half that of the rest of the brick, so that fluctuations of temperature would cause great strain to be set up between these two parts of the brick, with the consequent cracking off of the inner darker layer.

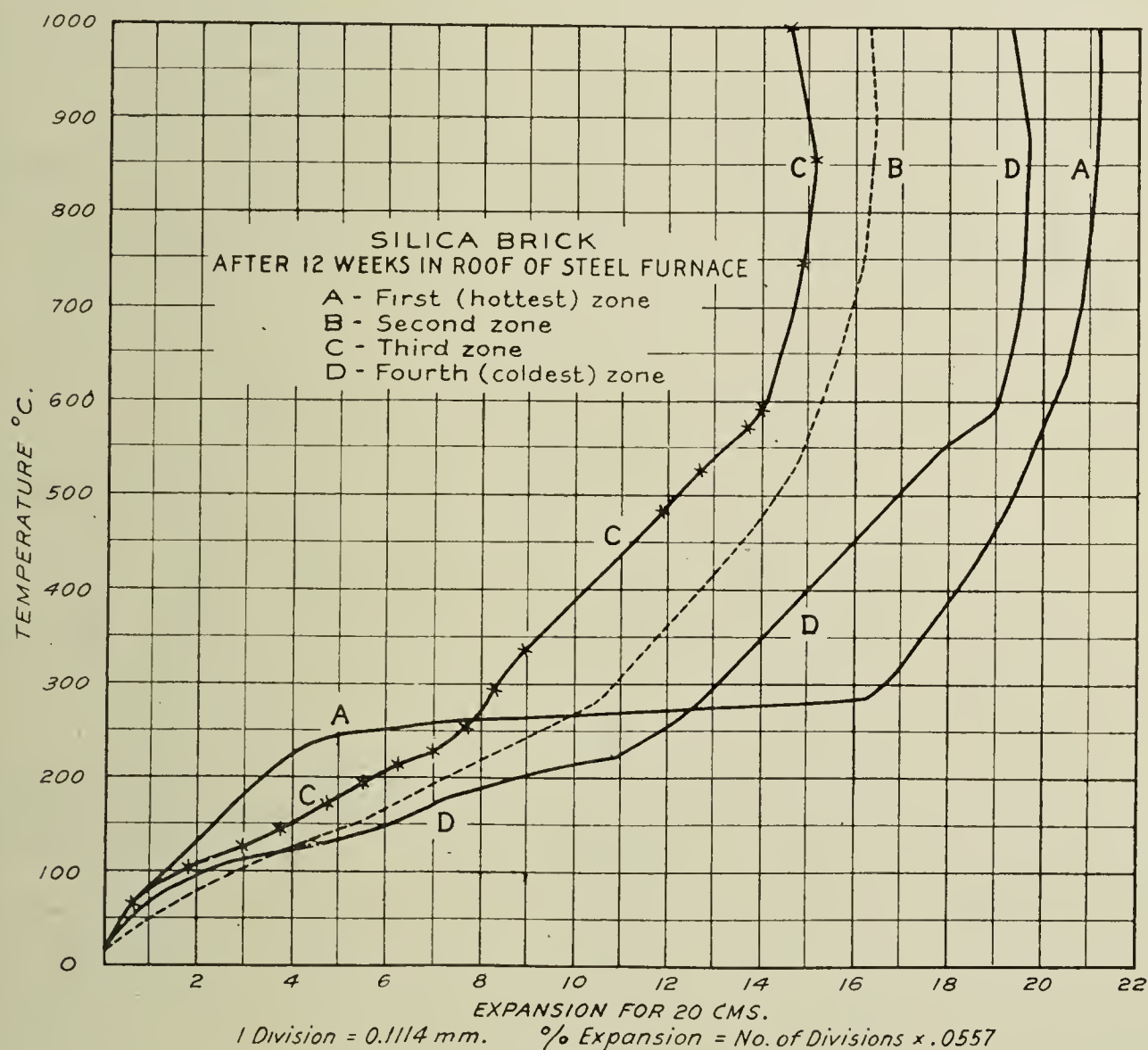


FIG. 10.

Silica Brick after Use in the Roof of a Steel Furnace

Commercial silica brick made from the Welsh quartzite used in this investigation were examined "after twelve weeks' use at a probable maximum temperature of 1600° to 1650°C in the roof of an open hearth steel furnace." On splitting each brick showed four fairly distinct layers (see Fig. 9).

(a) **Innermost Layer Next the Face Exposed in the Furnace and Highest in Temperature.** (Fig. 10, curve A.)—A test-piece was cut from this layer of the brick and examined in the apparatus. It expanded

steadily from 15° to 240°C but from this point to 280°C a large and rapid expansion took place so that the temperature-expansion graph was almost parallel to the expansion axis. From 280° to 630°C the rate of expansion was less than from 15° to 240°C. No discontinuity in the expansion was detected at 550° to 600°C such as would be expected if free quartz was present. The coefficient of expansion above 630°C continually decreased until no further expansion occurred between 900° and 1000°C. The large expansion from 240° to 280°C was reversible on cooling but occurred at a lower temperature (220° to 200°C). It was presumably due to the α to β cristobalite inversion. Apparently neither quartz nor tridymite were present in quantity. Microscopic examination showed that the bulk of the material was cristobalite having a refractive index between 1.503 and 1.481. About one-eighth of the powder had an index of refraction greater than 1.503 and probably consisted of silicates. A small quantity had a refractive index less than 1.481 and was probably tridymite.

TABLE I
CHEMICAL ANALYSES OF THE MATERIALS EXAMINED

	Raw kaolin	Raw Farnley fire clay	Ayrshire bauxitic clay	Calcined alumina +10% ball clay	Magnesia brick	Welsh quartzite without bond	Silica brick A	Silica brick C	Silica brick A after use in coke oven, 1st innermost layer
Hygroscopic mois- ture.....	0.14	..	0.75	..	..	..	..	..	..
Loss on ignition...	12.78	9.36	13.96	..	..	0.26	..	..	0.11
Silica (SiO ₂).....	46.20	63.48	36.65	5.4	5.80	98.78	93.79	94.24	87.21
Alumina (Al ₂ O ₃)...	38.49	22.39	43.83	94.2	1.75	0.12	1.56	1.32	4.16
Titanium dioxide (TiO ₂).....	..	1.10	3.20	..	..	0.12	0.12	0.25	0.27
Ferric oxide(Fe ₂ O ₃)	0.85	1.33	0.67	0.13	9.71	0.91	1.30	1.69	3.0
Lime (CaO).....	0.30	0.70	0.49	0.01	2.15	0.08	3.07	1.79	3.36
Magnesia (MgO)...	0.19	0.52	0.00	0.01	79.92	Tr.	Tr.	0.04	0.01
Soda (Na ₂ O)...	0.81	0.88	} 0.57	0.01	..	} 0.27	} 0.15	} 0.63	1.09
Potash (K ₂ O)....	0.65	0.47		0.01	..				1.35

Second Layer of Brick Used in Roof of Steel Furnace.—This part of the brick expanded quite differently from the hottest portion. (Fig. 10, curve B.) Its length increased steadily and at a fairly rapid rate to 300°C, after which the rate of expansion decreased gradually with increasing temperature until there was a slight contraction between 900° and 1000°C. The cooling curve was similar to the heating curve. No marked discontinuity occurred. The total expansion to 1000°C was about four-fifths, and that from 15° to 300°C about three-fifths, of that of the hottest layer, again showing the possibility of strains and cracks developing owing

to the different rates of expansion of the two layers. Examination of the powdered sample showed about half the material had a refractive index greater than 1.503, that of the other half being between 1.503 and 1.481. A very few particles had a refractive index less than 1.481 and were prob-

TABLE II

POROSITY AND BULK AND FINE SPECIFIC GRAVITIES OF THE MATERIALS TESTED

$$\left(\text{Porosity} = \frac{\text{Wt. of paraffin absorbed by specimen}}{\text{Loss in wt. of saturated specimen on weighing in paraffin}} \right)$$

$$\left(\text{Bulk specific gravity} = \frac{\text{Wt. of specimen}}{\text{Total volume of specimen}} \right)$$

	Temp. of previous burning	Porosity	Bulk sp. gr.	True sp. gr.
Kaolin.....	Cone 06	47.4	..	..
	Cone 9	34.6	..	..
	Cone 14	23.0	..	..
	Cone 20	0.4	..	..
Farnley fire clay.....	Cone 06	31.7	..	..
	Cone 9	28.7	..	..
	Cone 14	25.8	..	..
	Cone 20	1.4	..	..
Ayrshire bauxitic clay.....	Cone 06	30.7	..	..
	Cone 9	28.4	..	..
	Cone 14	26.9	..	..
	Cone 20	4.2	..	..
Magnesia brick.....	Cone 06	33.9	..	..
	Cone 9	33.9	..	..
	Cone 14	27.8	..	..
Carborundum with clay bond.....	Cone 20	31.9 ¹	.	..
Alumina.....	Cone 9	72.1	..	..
Welsh quartzite with bond.....	Unfired	..	..	2.64
	Cone 06	34.4	1.68	2.63
	Cone 9	36.6	1.62	2.58
	Cone 14	39.7	1.43	2.35
	Cone 20	44.7	1.28	2.33
Silica brick A.....	.....	26.0	1.78	2.40
Silica brick B.....	.....	26.8	1.76	2.40
Silica brick C.....	.....	27.9	1.68	2.35
Silica brick A after use in coke oven				
1st (next the exposed face) layer...	.....	20.6	1.89	2.37
Second layer.....	.....	29.0	1.67	2.33
3rd layer.....	.....	29.6	1.62	2.30
4th layer.....	.....	30.1	1.59	2.28
Silica brick A after use in roof of steel furnace				
1st (hottest) layer.....	.....	8.6	2.24	2.45
2nd layer.....	.....	7.3	2.27	2.45
3rd layer.....	.....	5.3	2.19	2.32
4th layer.....	.....	28.1	1.72	2.39

¹ Blistered

ably tridymite. Thus microscopic examination indicated that almost half the material in this layer was cristobalite while the other half had a refractive index greater than 1.503. As no quartz was detected in the expansion test the latter portion was probably chiefly silicates. A very small amount of tridymite was also present.

Third Layer of the Brick Used in Roof of Steel Furnace. (Fig. 10, curve C.)—The total expansion from 15° to 1000°C of the third layer was not very different from that of the second layer but the form of the curve was somewhat different and there was evidence of the α to β quartz inversion. The microscopic examination of the powdered material gave similar results to those obtained for the second layer, but taking these in conjunction with the expansion of the test piece it seemed probable that some quartz and less silicates were present along with cristobalite in quantity.

Fourth Layer of Brick Used in Roof of Steel Furnace. (Fig. 15, curve D.)—The expansion of this test piece did not differ appreciably from that of the unused brick, and microscopic examination of the powdered material immersed in oils of known refractive indices also gave similar results to those obtained for the unused bricks, *i. e.*, this layer consisted of a mixture of quartz and cristobalite with a very small amount of tridymite.

The volume changes in manufacture and use of a silica brick may therefore be traced thus.

First, on burning, the quartz undergoes a permanent linear expansion, with little or no decrease in specific gravity, but an increase in porosity. This permanent expansion may be about one-half per cent even below 1000°

TABLE III
COEFFICIENTS OF EXPANSION $\times 10^{-7}$

Substance	Temp. range (°C)	Un- fired	Temperature of prior firing			
			Cone 06	Cone 9	Cone 14	Cone 20
Kaolin.....	100-250	...	..	76.4	57.8	..
	15-1000	...	40.2	53.1	47.7	44.1
Farnley fire clay.....	100-250	...	..	102.3	87.5	..
	15-500	...	48.1	76.9	67.6	..
	500-600	...	133.1	127.5	107.5	..
	600-1000	..	21.7	18.3	25.0	..
	15-1000	...	49.1	58.3	54.0	30.5
Ayrshire bauxitic clay.....	100-250	...	..	72.6	65.2	..
	15-1000	...	48.0	60.5	56.1	41.8
Carborundum.....	15-1000	...	..	47.1	47.8	38.6
Magnesia brick.....	15-1000	...	127.4	127.4	135.1	..
Welsh quartzite with lime bond....	15-1000	136	122	128	155	153
	15-500	163	172	192	279	298
	200-250	...	..	396	1454	1721
	500-600	579	417	289	139	44
	600-1000	-4	-4	14	11	7

TABLE III (Continued)

COEFFICIENTS OF EXPANSION $\times 10^{-7}$

Substance	Temp. range (°C)	Un- fired	Temperature of prior firing			
			Cone 06	Cone 9	Cone 14	Cone 20
Silica brick A.....	15-1000	...	118	..	..	..
	15-250	...	304	..	..	..
	250-500	...	101	..	..	..
	500-600	...	127	..	..	..
	600-1000	...	17	..	..	..
Silica brick B.....	15-1000	...	131	..	..	..
	15-250	...	344	..	..	..
	250-500	...	108	..	..	..
	500-600	...	111	..	..	..
	600-1000	...	23	..	..	..
Silica brick C.....	15-1000	...	107	..	..	..
	15-250	...	280	..	..	..
	250-500	...	84	..	..	..
	500-600	...	61	..	..	..
	600-1000	...	31	..	..	..
Silica brick A after use in coke oven						
(a) Innermost layer.....	15-1000	...	65	..	..	..
(b) Other layer.....	15-1000	...	121	..	..	..
	15-250	...	340	..	..	..
Silica brick A after use in roof of steel furnace						
(a) Innermost (hottest) layer....	15-1000	...	125	..	..	..
	200-300	...	746	..	..	..
(b) Second layer.....	15-1000	...	98	..	..	..
	15-250	...	231	..	..	..
(c) Third layer.....	15-1000	...	88	..	..	..
	100-250	...	232	..	..	..
	250-500	...	106	..	..	..
	500-600	...	117	..	..	..
	600-1000	...	13	..	..	..
(d) Fourth (coldest) layer.....	15-1000	...	115	..	..	..
	100-250	...	369	..	..	..
	250-550	...	117	..	..	..
	550-600	...	139	..	..	..
	600-1000	...	12	..	..	..

$\times 220-270^{\circ}\text{C}$

C and two per cent up to cone 9. The toughness may appreciably alter in consequence. The further burning to cone 14-16 alters the expansion curve changing the quartz completely or partially according to the nature of the raw material and the time and temperature of burning into cristobalite. This means that the sudden α to β quartz expansion between 500° and 600°C is replaced by the α to β cristobalite expansion between 200° and 300°C . The total reversible expansion is not lessened. The furnace of "cristobalite" bricks is therefore much less subject to expansion strain

at dull redness than one of "quartz" bricks, although more so below 300°C. Neither is at all sensitive above 600°C. Long exposure in use at high temperatures completes the conversion of quartz to cristobalite. Apart from actual test in the expansion apparatus, we have found that a determination of the true specific gravity of the powdered brick is the best guide to its behavior as regards expansion and contraction.

(Specific gravity of quartz = 2.65)

(Specific gravity of cristobalite = 2.33)

The chemical analyses of the materials examined are given in Table I, the porosity of the test-pieces and the specific gravity of the silica specimens in Table II, and their coefficients of expansion in Table III.

FUEL DEPARTMENT
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REFRACTORY POSSIBILITIES OF SOME GEORGIA CLAYS¹

BY R. T. STULL² AND G. A. BOLE³

Introduction

Of the different raw materials used in the manufacture of refractories, clay must be relied upon in the future, as in the past, to furnish the bulk of commercial refractories because of its greater abundance, wider distribution, and broader application.

It has been stated⁴ that the best fire clays of Pennsylvania, Maryland, Ohio, and Kentucky, within reach of railroads, are waning rapidly and that the average quality of the fire clay refractories classed as number one has fallen off within the last 15 to 20 years. It must, of course, be recognized that there are fire clay refractories on the market at the present time as good as any made in the past, but the bulk of such, as a class, has evidently decreased in refractoriness from one to as much as three cones.

Several plants have experienced difficulty in finding sufficient available flint clay of good quality to supply their needs, while others have exhausted their number one plastic clay and have been compelled to use bond clays of lower refractory value.

The Ohio Geological Survey in coöperation with the United States Bureau of Mines has completed an investigation of the fire clays of the State.⁴ Of 86 clay samples tested, mostly from the mines of operating plants, only 16 samples were sufficiently refractory to soften at or above cone 31, thus qualifying as suitable clays for the manufacture of high duty refractories. Twelve of these were flint clays and four were semi-flint. The most refractory ones softened at cone 33 and no bond clays were found in the State of sufficient refractoriness to fall within the high-duty class. The nearest to it were two plastic clays deforming at cone 30¹/₂.

It was also found that some plants were bonding their high-grade flint clays with plastic clays deforming at cone 29 down to as low as cone 23. Bleininger and Brown have pointed out that a fire brick under load at furnace temperatures⁵ is no better than its bond.

The broader application of the electric furnace to the metallurgical and chemical industries, the development of new processes, automatic stoker-fired boilers and the broader application of forced draft to furnaces have created a demand for a more serviceable fire brick of higher refractory value. Such a brick can be made from kaolins and highly aluminous clays.

¹ Published by permission of the Director, U. S. Bureau of Mines.

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⁴ "Coal Formation Clays of Ohio," *Bulletin*, 26, Ohio Geological Survey. (In press.)

⁵ A. V. Bleininger and J. H. Brown, *Trans. Amer. Ceram. Soc.*, 12, 341 (1910).

Economic Factors

Through the middle of Georgia from Northeast to Southwest runs a belt, known as the coastal plain, 220 miles long and from 25 to 50 miles wide, containing secondary kaolins, bauxitic clays and bauxites in abundant quantities.

These clays were derived from the decomposition of crystalline rocks of the Piedmont Plateau to the North and were washed down and deposited on the coastal plain where beds were formed from a few feet to over 40 feet in thickness.

Nature evidently conducted a clay-washing process on an enormous and efficient scale, for many of these clays are snow-white, very fine grained and comparatively free from impurities. All are very refractory.

The theory has been advanced that bauxites were derived from the alteration of the kaolins. This is indicated by the fact that deposits occur varying in composition all the way from kaolin on the one hand to bauxite on the other.

Many of the fine white clays are produced for the filler trade and several of the white burning ones are used for pottery making purposes.

The kaolins are plastic and mold readily and many of them show a fairly good dry tensile strength. As the alumina content of the clays increases above the kaolinite ratio, their plasticity and slaking tendency decrease and, with rare exceptions, their iron content increases with the alumina. Kaolins and bauxitic clays, which may not be suitable for fillers or pottery, fuse at a very high temperature and, therefore, are valuable for the manufacture of refractories.

Bleiningger and Brown¹ point out the advantage of using the same clay for grog and bond, as follows:

“As to fire brick made from a clay material which is sufficiently plastic so as to be used alone, it is clear that its ability to carry loads depends simply upon its composition. Some of the very best tests have been obtained on materials of this kind. . . . Such a clay will stand up or fail by virtue of its own quality. A pure clay of moderate plasticity would be the ideal material for the manufacturing of fire brick.”

The Central of Georgia Railway Company entered into a coöperative agreement with the Bureau of Mines to investigate the pottery making, filler, and refractory properties of the kaolins, bauxitic clays, and bauxites along the Railway's right of way.

Thirty samples of from 500 to 2,000 pounds each were selected in a manner to represent the different types in the field. Some of these clays were found to be valuable for pottery making purposes, while others were especially suited to the filler trade. They were all refractory. The de-

¹ *Loc. cit.*

formation temperatures of the clays tried out for use in the ceramic field varied from cone 33 as the lowest to cone 39 plus for the highest. Of these clays,

- 2 Samples deformed at cones 33 to 34
- 14 Samples deformed at cones 34 to 35
- 3 Samples deformed at cones 35 to 36
- 1 Sample deformed at cones 36 to 37
- 3 Samples deformed at cones 38 to 39
- 1 Sample deformed above cone 39

In the fire brick industry, most of the flint and plastic fire clays are obtained by underground mining. Often it is necessary to move considerable inferior clay to obtain the desirable refractory clay. Underground mining

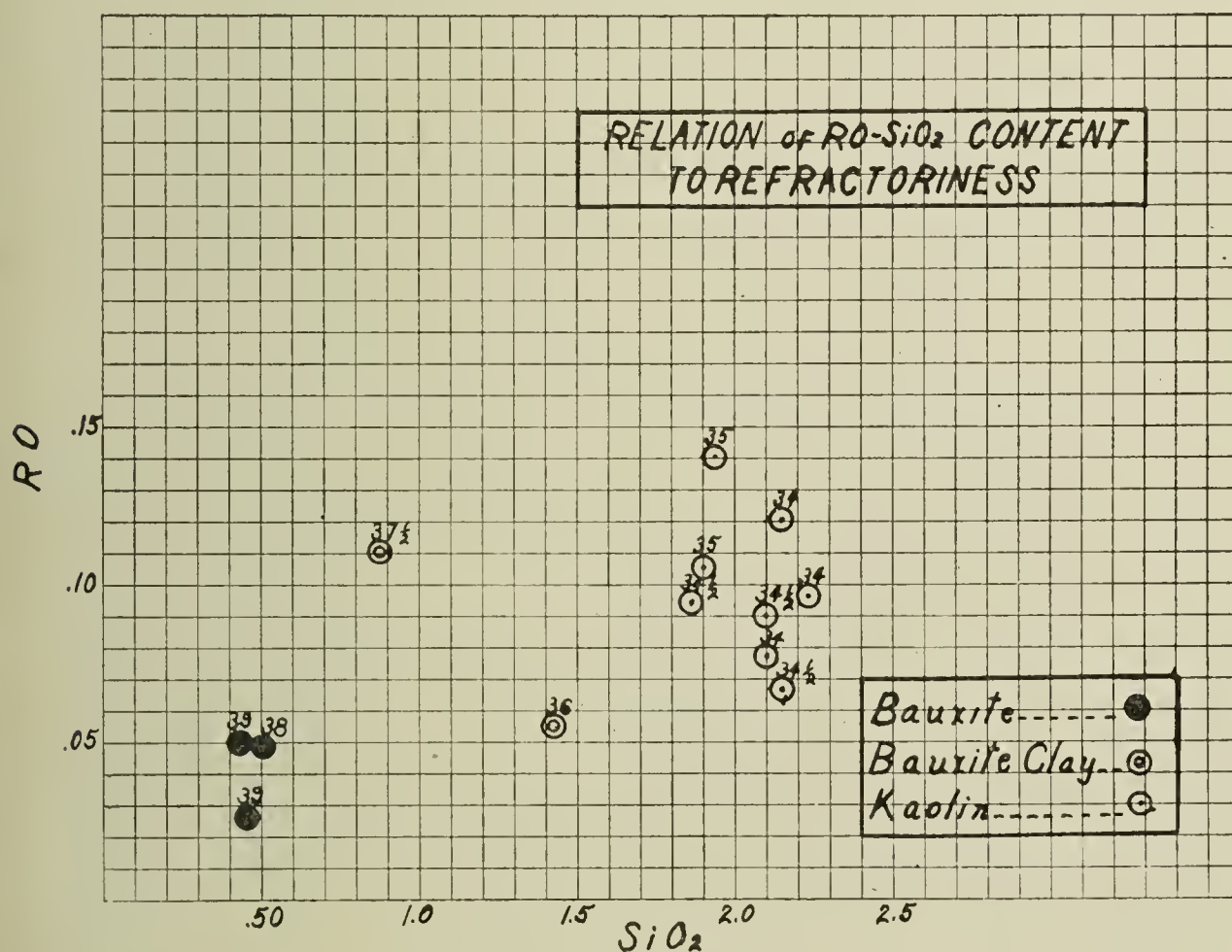


FIG. 1.

is comparatively expensive. Often it is necessary to move a ton of inferior clay to get a ton of number one clay. The clay cost delivered at the plant may vary from one to two dollars per ton and in some cases it amounts to even more.

The kaolins and bauxites of Georgia were essentially surface deposits which have been covered with an overburden that varies from 3 to 40 feet in depth. Several deposits of substantial thickness are covered with comparatively thin overburdens. One deposit in particular is 28 to 40 feet in thickness. It is covered with an overburden that ranges from one foot in thickness along a ravine, up to 14 feet and will average about 8

TABLE I
CHEMICAL ANALYSES

Clay no.	G-1	G-3	G-5	G-7	G-10	G-11	G-12	G-13	G-14	G-15	G-19	G-20
Moisture												
105°C.....	2.05	1.15	.98	.99	.35	.52	.89	.57	.46	.74	.60	.53
L.O.I.....	12.67	13.33	12.73	13.42	24.07	14.13	25.89	21.97	25.41	13.79	13.23	17.17
SiO ₂	45.61	46.56	45.78	43.82	16.09	42.59	14.08	24.80	14.42	43.25	46.56	35.95
Al ₂ O ₃	36.15	35.51	37.01	38.26	55.48	38.04	55.34	47.99	56.23	39.45	36.57	43.32
Fe ₂ O ₃	1.47	1.59	1.11	1.44	1.77	1.59	1.65	1.92	.96	.96	.99	1.35
TiO ₂.....	.77	1.29	1.32	1.60	2.04	2.34	1.98	1.88	2.34	1.17	1.48	1.60
P ₂ O ₅.....	.05	.05	.06	.05	.06	.08	.07	.04	.01	.04	.01	.06
CaO.....	.80	.39	.35	.17	.16	.88	.14	.95	.31	.24	.35	.14
MgO.....	.30	.25	.18	.10	.08	.12	.06	.21	.12	.11	.24	.11
K ₂ O.....	.43	.00	.75	.13	.00	.00	.04	.00	.00	.16	.00	.00
Na ₂ O.....	.00	.00	.03	.29	.00	.00	.06	.00	.00	.38	.00	.12
Sulphur.....	.02	.03	.06	.02	.02	.05	.05	.03	.06	.15	.01	.03
Cone.....	34	34	34 1/2	35	38	35	39	37 1/2	39	34 1/2	34 1/2	36

feet. Such a clay can be mined by stripping, and delivered to the plant at a cost of approximately 20 to 30 cents per ton.

Laboratory Tests

Of the above-mentioned 30 clays, 13 were tested for refractory purposes. The chemical analyses and deformation cone are given in Table I. In Fig. 1 are plotted the RO-Al₂O₃-SiO₂ ratios of the several clays. The iron is figured as FeO. TiO₂, P₂O₅, and S are omitted from the calculations shown in the diagram. These clays seem to owe their high refractoriness in most part to their low RO in general, and in particular to low alkali content. Besides the ordinary laboratory tests to determine the physical properties of these clays, full-sized fire brick were made and tested under load at furnace temperatures, spalling tests were run, and porosity determinations made.

The brick were made from a mixture of 60%, ten-mesh grog, calcined to cone 13, and 40% of the same raw material as bond. The brick were molded dry press and fired to cone 14. Data showing the physical characteristics of the clays are shown in Table II.

TABLE II

LABORATORY TESTS ON CLAYS GROUND TO 150-MESH

Sample number	Tempering water	Drying volume shrinkage	Drying linear shrinkage	Volume shrinkage cone 11	Linear shrinkage cone 11	Porosity ¹
G-1	41.06	24.83	7.70	40.05	15.68	29.20
G-3	35.76	17.05	5.40	43.41	17.29	40.70
G-5	38.50	22.68	7.10	38.01	14.74	22.82
G-7	35.20	18.71	5.90	41.88	16.55	36.20
G-10	28.60	11.03	3.50	44.77	17.95	27.77
G-11	39.66	20.38	6.40	43.09	17.13	24.30
G-12	29.68	14.49	4.60	47.10	19.12	29.56
G-13	32.80	7.53	2.50	45.15	18.14	27.05
G-14	33.83	12.90	4.10	47.87	19.52	19.46
G-15	38.73	15.83	5.00	37.32	14.42	25.72
G-19	42.40	13.34	4.30	52.17	21.79	55.10
G-20	30.13	11.32	3.70	44.86	18.00	15.93
G-23	38.10	26.66	8.10	32.09	12.09	15.03

Note: The above figures represent per cent figured on basis of dry clay and test pieces.

The physical characteristics of the brick, made from the several clays and bauxites and burned to cone 14 are shown in Table III.

A second lot of brick was made from bauxites G-10 to 14, inclusive, and tested for spalling and load capacity at furnace temperatures. These

¹ All porosity determinations were made in the air expansion volumeter, and are, therefore, slightly higher than porosities determined by the saturation method.

brick were made dry press from a mixture of 70% of the bauxite calcined to cone 14 and bonded with 30% of kaolin G-3 and the brick fired to cone 16. Results of the tests are shown in Table IV.

TABLE III

TESTS ON DRY PRESS BRICK

Sample no.	Deformation temperature (cone)	Porosity cone 14 (per cent)	Spalling loss (per cent)	Load tests (lbs. per square inch)
G-1	34	28.28	0.50	1830 lbs. without failure, 1330°C
G-3	34	28.78	0.00	1830 lbs. without failure, 1330°C
G-5	34½	33.55	0.17	50 lbs. without failure, 1420°C
G-7	35	27.79	.34	50 lbs. without failure, 1420°C
G-10	38	44.20	13.15	Not tested
G-11	35	39.32	16.95	Not tested
G-12	38+	42.65	22.40	Not tested
G-13	38	43.75	25.15	Not tested
G-14	39+	42.81	18.30	Not tested
G-15	34+	35.83	0.58	50 pounds without failure, 1420°C
G-19	34+	41.45	14.15	50 pounds without failure, 1420°C
G-20	35+	36.87	0.52	50 pounds without failure, 1420°C
G-23	33	35.48	9.25	50 pounds without failure, 1420°C

Samples G-10 to G-14 inclusive are bauxites. The brick made from these materials were friable and of a very weak structure and should be burned considerably above cone 14 in order to give them the mechanical strength to withstand spalling and load.

They are comparatively low in plasticity, and hence do not mold as readily as a kaolin bonded brick.

TABLE IV

Sample no.	Porosity (per cent)	Spalling loss (per cent)	Load test (1350°C)
G-10	36.80	5.62	Failed at 691 lbs. per sq. in.
G-11	16.05	..	Cracked in burning. Not tested
G-12	31.60	0.39	Failed at 847 lbs. per sq. in.
G-13	35.40	1.68	Failed at 870 lbs. per sq. in.
G-14	39.20	5.14	Failed at 640 lbs. per sq. in.

Even though bonded with kaolin and fired to cone 16, these brick were not burned hard enough to give them best strength and lowest spalling loss. Their appearance indicated that they would have been improved if burned at cone 18. However, G-12 and G-13 gave very good results in both the spalling and load tests.

Large Scale Tests on G-3

Kaolin G-3 is typical of a number of deposits of the Georgia Coastal Plain. This kaolin was, therefore, selected for the large scale tests. A carload was shipped to a fire brick plant and made into standard sized fire brick by the slush mold-repress process in the regular manner. These

brick were made from 60% of the clay calcined (in "dobies") to cone 14 and 40% of the raw clay as bond. The calcined and raw clays were ground together and tempered without screening, according to the regular plant practice. The brick were burned in the kiln in three benches to cones 10, 11, and 14. The total linear shrinkage of the cone 14 brick calculated on the burned length as basis was five and sixty-seven hundredths per cent. Half of this was dry shrinkage and half burning shrinkage.

The average weight of several standard sized kaolin fire brick was 6¹/₂ pounds, as compared to seven pounds average weight of standard sized fire-clay fire brick. The difference of a half pound in weight per brick, therefore, means a saving of 500 pounds per thousand brick, an item which comparatively reduces freight cost materially. Every ton saved in the refractories for boiler settings in naval craft and ocean-going liners means a ton increase in displacement for ammunition, fuel, or freight.

Spalling and load tests at furnace temperatures were made on brick burned at cone 14 in comparison with a well-known Pennsylvania flint fire-clay brick of excellent qualities. The results of the tests were as follows:

Deformation temperature	(cone)	Porosity (per cent)	Spalling (per cent)	Load at 1350°C
G-3 brick,	34	34.0	2.22	Withstood 733 lbs. per sq. in. without failing. (Max. capacity of machine.)
Penna. brick,	31	20.8	1.52	Failed at 485 lbs. per square inch.

Service Tests

Malleable Iron Furnace.—A bung of 40 G-3 brick burned at cone 10 was tested in a malleable iron furnace of the Ohio Malleable Iron Company at Columbus, Ohio. The bung was tested in the most severe position in the furnace which is directly above the bridge wall where the fire gases leave the furnace and start their passage over the hearth and burden of metal to be melted. When operating at one heat per day, the furnace is heated and cooled slowly so that the conditions are not severe on the brick, but when operated at two heats per day, the heating and cooling are done rapidly, thus imposing more severe treatment upon the brick, and their life is thereby materially shortened.

Two brands of brick, one from Pennsylvania and one from Missouri, had been found by the Company to give maximum service. When the furnace was operated at one heat per day, these brick would last for eighteen to nineteen heats, but when the furnace was operated at two heats per day their life averaged only 11 heats.

The G-3 brick withstood 11 heats with the furnace operating at two heats per day. The brick showed no evidence of failure through corrosion, as was the case in the two commercial brands, but they failed through

spalling. The brick used showed an average porosity of 32.8% and a spalling loss of 7.98% as compared to a porosity of 32% and a spalling loss of 2.22% for the brick burned to cone 14. Even though these brick were not burned hard enough to withstand spalling, they gave as good service as

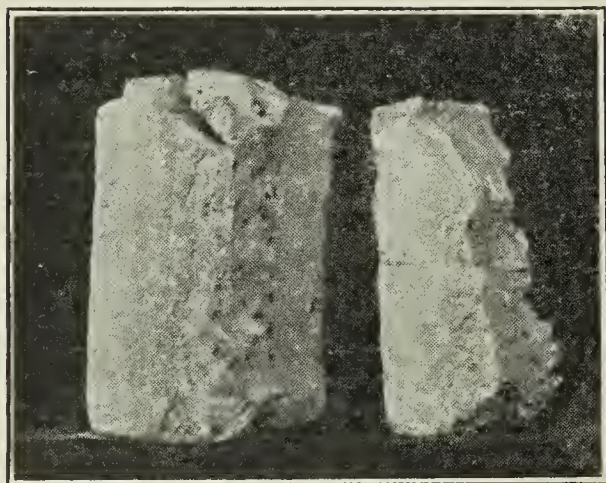


FIG. 2.—Brick removed from bung at end of eleven heats; (left)—kaolin, (right)—fire clay.

the best commercial bung brick the plant has been able to obtain. A bung of 40 brick burned to cone 14 was later tested and lasted through 11 heats. The brick were in much better condition at the end of the test than were the cone 10 brick. The condition of the cone 14 brick, as compared to the Pennsylvania brick at the end of the test, is shown in Fig. 2.

Company of Columbus, Ohio. After a long series of experiments on different types and brands of brick, the plant has adopted a silica brick as one giving maximum service.

The furnace is provided with two doors, one at each end. One door was lined with silica brick and the other with G-3 kaolin brick. Brick in these doors, in addition to receiving a high temperature, must withstand the cutting action of slag and metal which is continually thrown against them by the furnace arc.

The silica brick failed after 48 heats as compared to 62 heats served by the G-3 fire brick, an increase of 14 heats or almost 30%. When the two doors were removed, their appearance was substantially the same. Records of tests at the plant show that fire-clay fire brick fail on the average after about 35 heats.

The kaolin brick showed no tendency to spall. Failure was finally due to the fact that the door was corroded at the bottom until too thin for safety.

There was almost no penetration of the slag, as is clearly shown in Fig. 3, which is a photograph of the brick removed from the badly corroded portion of the door.

Electric Furnace Roof.—The third span from the door in the silica brick crown of the Ludlum electric furnace was laid up with the kaolin brick in

Electric Furnace Doors.—Tests were made on G-3 fire brick placed in a door of a three-ton Ludlum electric steel melting furnace of the Bonney Floyd

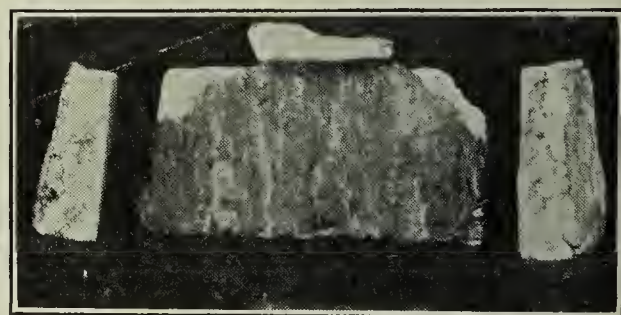


FIG. 3.—Kaolin brick removed from electric furnace door at end of 62nd heat.

order to compare their service as against that of the silica brick. Practice at this plant was to operate a roof for two weeks and to put in a new one over the week end. At the end of the two weeks the brick would often be good enough to last much longer, but since only one furnace was in operation, no chances were taken of having a roof fail during the week. As the roof in which the test was being run was in good shape at the end of two weeks, it was decided to use it for another week in order to make the test more severe.

The entire crown was in fairly good shape at the end of the third week. The kaolin brick were in as good shape as the silica brick on either side



FIG. 4a.—Silica brick removed from roof of electric furnace after three weeks, service.

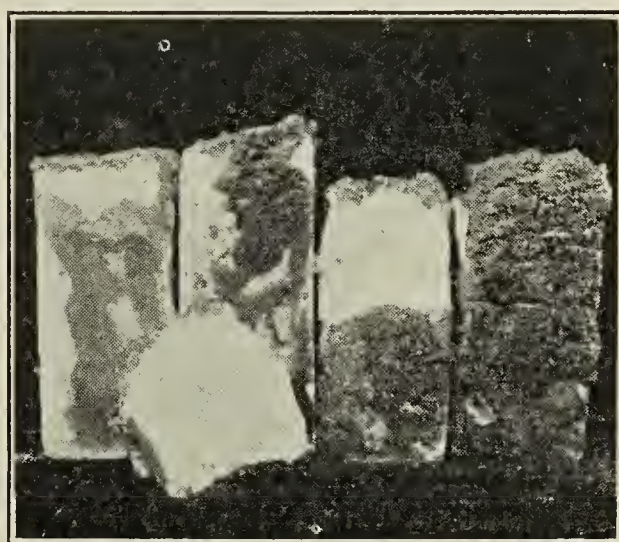


FIG. 4b.—Kaolin brick removed from roof of electric furnace after three weeks' service.

of them. In Figs. 4a and 4b are shown brick removed from the crown at the end of the test. The silica and kaolin brick were side by side in the setting.

It will be noted on the portion broken from brick that there has been less penetration in the case of the kaolin than in the silica.

Ladle Lining.—At the plant of the Bonney-Floyd Company, tests are also in progress to determine the behavior of these brick as ladle linings. Fifteen of the brick were placed in the bottom of an open-hearthed ladle, where difficulty is experienced in getting ordinary fire brick to “hold up” due to the fact that they must withstand heating to the temperature of molten steel and then water cooling between heats. Under this treatment ordinary fire brick fail after two or three weeks through spalling and disintegration. The 15 G-3 fire brick were placed in service January 19, and have shown no signs of spalling or crumbling up to the present time (April 7). They have, therefore, been in service over 11 weeks without showing signs of failing.

Boiler Setting.—Trouble was being experienced in securing proper refractories for the side walls in a stoker-fired fire box at the heating plant at Ohio State University.

Carborundum brick are used along the fuel bed and are giving good service, but due to local heating produced by the stoker, the fire-clay brick immediately above the fuel bed are dripping badly. One hundred of the kaolin brick burned to cone 14, which were placed in a side wall immediately over the carborundum, are standing up well while a Kentucky fire brick, recommended for the service by a local dealer, has been cut away badly on both sides of the kaolin brick. The test has not been in progress long enough to foresee the final outcome, but it is evident that the kaolin fire brick will outlast the fire-clay fire brick by a considerable margin.

Oil-Fired Furnaces

Two hundred of the G-3 brick burned to cone 14 were laid up in a checker baffle in the combustion chamber of an oil fired Wickes vertical tube boiler at a Gary, Indiana plant. The flame was supposed to impinge on a target before coming in contact with the baffle, although at times the flame licked the wall. A temperature of from 2800° to 3000°F was said to obtain at the baffle. The best grades of fire brick had a life of from 48 to 96 hours, depending upon the length of the oil flame. The kaolin brick held up fairly well for about eight days, although they began to pull away from the walls after 48 hours, evidently due to shrinkage. Highly aluminous brick held up somewhat better than the kaolin brick under the same circumstances. The failure in all cases was due to the intense heat and the corrosive action of the oil flame.

The test was not very satisfactory as the failure was so gradual that no end point could be determined. The life of the different refractories tried out varied enormously among themselves, depending on whether the flames actually impinged upon the brick being tested.

Conclusions

The Georgia sedimentary kaolins, bauxitic clays, and bauxites tested show deformation values from cones 34 to above cone 39; showed superior load carrying capacity and good resistance to spalling.

Enough work has been done to demonstrate the fact that these refractory materials can be made into fire brick in a practical way both by the dry press and slush mold-repress processes.

Furnace tests under actual working conditions have shown that the service rendered by fire brick made from Georgia sedimentary kaolins were at least equal to and in the majority of cases superior to fire clay and silica fire brick.

Inasmuch as the high-grade accessible fire clays are waning, the average quality of the fire brick decreasing, and the demand for better fire brick increasing, it would appear that the future of the fire brick industry lies in the utilization of the sedimentary kaolins, bauxitic clays, and bauxites of the coastal plain. Vast areas are underlaid with deposits of such substantial thickness that there is enough high-grade material to meet the needs of the refractory industry for years to come.

GLASS WOOL HEAT INSULATION IN EUROPE

BY A. D. SABORSKY

Modern heat insulation is a comparatively young art. People who were apt to notice the tiniest leak of live steam, or who would worry about their water bills, when a faucet dripped, felt perfectly at ease and ignorant about the loss of heat from poorly insulated pipes. We all know that this attitude does not prevail today, and the steady growth of our insulation manufacturing concerns in the past decades is ample proof for it.

When we speak of high grade heat insulation here in U. S. A. we mostly involve the so-called asbestos insulations, of which asbestos forms only a small part (15% and less in the best insulations), and merely acts as a fibrous binder for the real insulating material, which is primarily carbonate of magnesia, a very friable and crumbling material. The more asbestos these insulations contain, the heavier they become, and the poorer in insulating value. Of other heat insulations used I may mention mineral wool, slag, some siliceous earth (Kieselguhr), clay, paper preparations, cork, and so on.

The demands made upon an ideal insulating material are so exacting and manifold that the heat insulating materials on the market today are only able to comply with a selected few of these specifications. Glass wool however has proved in practice as well as laboratory tests the closest to being an ideal heat insulator.

The following are the characteristics for an ideal heat insulation material:

1. Low conductivity
2. Low specific heat
3. Light weight
4. Withstand vibration
5. Withstand destruction by blows
6. Flexibility to
 - (a) Conform to most any shape
 - (b) Follow a surface, expanding under heat
 - (c) Withstand rough handling without damage
7. Withstand alternate heating and cooling
8. Withstand alternate wetting and drying
9. Easy, clean installation, possible by unskilled labor
10. Installation possible without stopping production
11. Contain a maximum of dead air cells
12. Be non-hygroscopic
13. Withstand extreme temperatures
14. Be proof against damage by steam, water, chemicals, air, rodents, etc.
15. Be comparatively cheap in cost and installation.

The first successful tests with glass wool for insulation purposes were made as early as 1904 in Bohemia (the present Czecho-Slovakia). The high qualities of glass wool as an insulating material were recognized right then, and even though the price, based on manufacturing methods then

in vogue, was almost prohibitive, it sold on its sheer quality for special insulations. Before the advent of the War there were already hundreds of chemical, textile, rubber, paper factories, etc., as well as some power stations and steam ships using and specifying this material in Central and Eastern Europe. The list includes firms as the Okulowska Paper Company of Moscow, which wrote September, 1913 "...We are using glass wool on superheated steam of 680°F , and also on saturated steam lines, as well as on our boilers and vats, and it supersedes all other insulations we used...." In one of their tests with an 8-inch glass wool insulated pipe, carrying superheated steam of 630°F and with a temperature of the surrounding air of 104°F , the drop in temperature per yard of pipe length was only $.46^{\circ}\text{F}$. The surface temperature of the insulation remained only 9°F higher than the surrounding air. In December, 1910, the Cautchouc Company of Riga, Russia confirm that they were very satisfied with the glass wool insulation on their Diesel engine exhaust pipes, stating that ".....with the motors under full load, the temperature difference between the surface and the surrounding air was only 35°C , and as you guaranteed 50°C , this guarantee has been well met. The thickness of our insulation is 70 mm. (about $2\frac{3}{4}$ inches)....." The Textile Company of the same town asserts in the same year, that ".....our glass wool insulation, which is steadily exposed to acid and water vapors is still in perfect condition....." Of the German concerns who installed this material before the War, I mention as some of the largest ones Friedrich Bayer & Company, who writes March, 1919, that ".....the insulations installed in 1910 are still in perfect order.....;" the large locomotive works of Orenstein & Koppel, the elevated Railway of Hamburg, the Royal Canning Factories of Spandau, the Wilhelmina Mine and many others.

In January, 1921, some steam hammers of the firm of Orenstein & Koppel, whose pipes had been insulated with glass wool way back in August, 1909, were dismantled. Their insulation had been in continuous use for almost 12 years, carrying steam of 470 to 550°F , being exposed all the time to the shocks and vibration, coincident with steam hammer practice, and when this insulation was removed the glass wool was found to have retained all its good insulation qualities and resiliency. Samples of this wool were labeled and attested by notary public (Fig. 1).

In 1914 the War started, and with it an immediate and entire lack of asbestos importations for Central Europe set in, aggravated by a still greater necessity for the preservation of fuel. Glass wool, whose excellent



FIG. 1.—After 12 years' service.

insulation qualities were already recognized, was then called upon irrespective of cost. A firm of ship chandlers in Hamburg, who up to that time had carried a line of asbestos insulations, started to supply the rapidly growing demand for glass wool, at first employing the crude manufacturing methods then available. Gradually as they found themselves unable to comply with the steadily increasing demand, different methods to im-

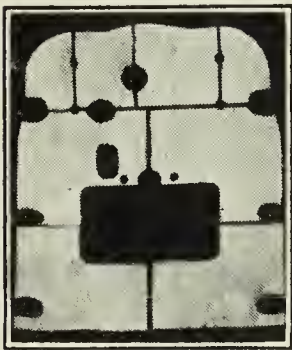


FIG 2.—Locomotive wire net mattress.

prove the manufacture were repeatedly tried, put into production and abandoned again, when better ways were discovered. In this way they covered the ground from the semi-manual making of glass wool from glass rods to present day automatic production directly from a vat of molten glass, with scrap glass as the raw material.

They finally succeeded in perfecting their machinery to such an extent, that today glass wool insulation is being sold not merely on account of its superiority, but is being offered at competitive prices.

Today, only four years since industries started to readjust themselves to peace conditions, there are thousands of factories and power stations specifying and buying glass insulation. Over 10,000 German government locomotives are already carrying glass wool insulation, which is especially desirable for this service, and also countries as Spain, Holland, Denmark, Roumania, Bulgaria, Hungary, Russia, Argentine, Brazil, and others are using it for the same purpose. (Figs. 2 and 3.) Due to its lightness and high qualities this material is absolutely without peer for insulation on shipboard, and I may mention as the latest ships thus equipped the "Resolute" and "Reliance" of the U. S. Line, the "Majestic," the latest and largest (58,000 T.), White Star Liner, the "Hansa"

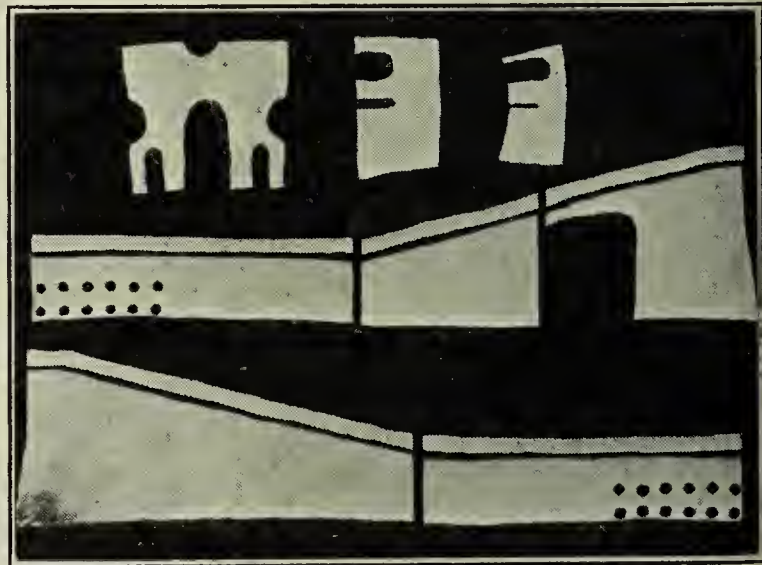


FIG. 3.—Fire box wire net mattresses.

of the Hamburg-American Line, the "Noordam" of the Holland-American Line, four ships of the German-Australian Line, at least six steamers of the South American Line, and many others. (Fig. 4.)

Of the largest manufacturing enterprises using glass wool today I select the following names.

Among Power Stations:

"Continental Rubber," Hannover

Reichardt Cocoa, Wandsbeck

Central Electric Station, Hamburg, etc.

Among Chemical Factories:

German American Oil Co., Hamburg
 Dessauer Sugar Co., Dessau
 Wolfen Film Co., Bitterfeld, etc.

Among Shipyards:

Blohm & Voss, Hamburg
 "Vulcan," Hamburg
 "Weser," Bremen
 and every other large German shipyard

On Steam Hammers

Maschinen Werkstätte Augsburg
 Bismarkhuette, Silesia
 Vulcan Werke, Hamburg; etc.

On Locomotives and Railroads:

Friedrich Krupp, Essen
 Borsig, Berlin
 Schwartzkopf, Berlin
 and practically all other locomotive builders

In Mining:

Laurahuette, Silesia
 Koenigshuette
 Bismarkhuette, etc.

Many laboratory tests were made by independent and unimpeachable authorities. Professor Oscar Knoblauch of the University of Munich, an international authority on thermodynamics, established the heat conductivity per cubic meter of glass wool, per one degree C surface difference per hour, as follows:

At 0°C	0.030 Calories
At 50°C	0.037 Calories
At 100°C	0.043 Calories
At 200°C	0.056 Calories
At 300°C	0.070 Calories

Above low figures have not been attained by any other heat insulation on the market, and have been proved repeatedly by different sources and in different countries, as by Professor Mitchel of the University of Moscow, by the Technical University of Prague, and a number of other high standing institutions in Europe. These figures have also been confirmed by a number of private enterprises having their own laboratories, and using glass wool insulation.

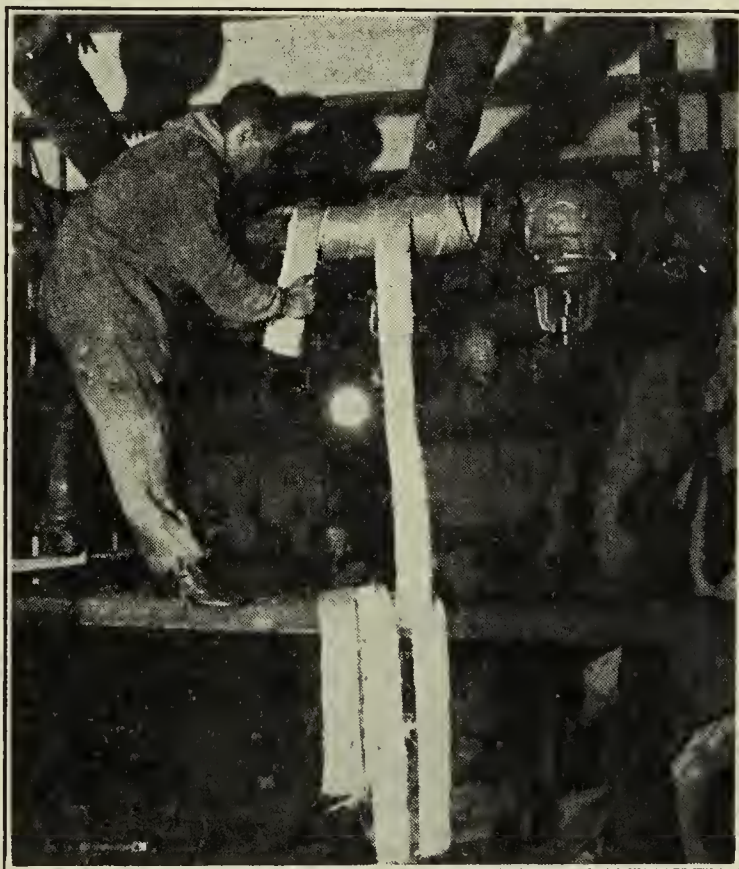


FIG. 4.—Band insulation on shipboard.

The factor of heat conductivity is the only scientific means for just comparisons and a table of curves displaying the conductivity of different materials shows glass wool insulation as the lowest curve. (Fig. 5.)

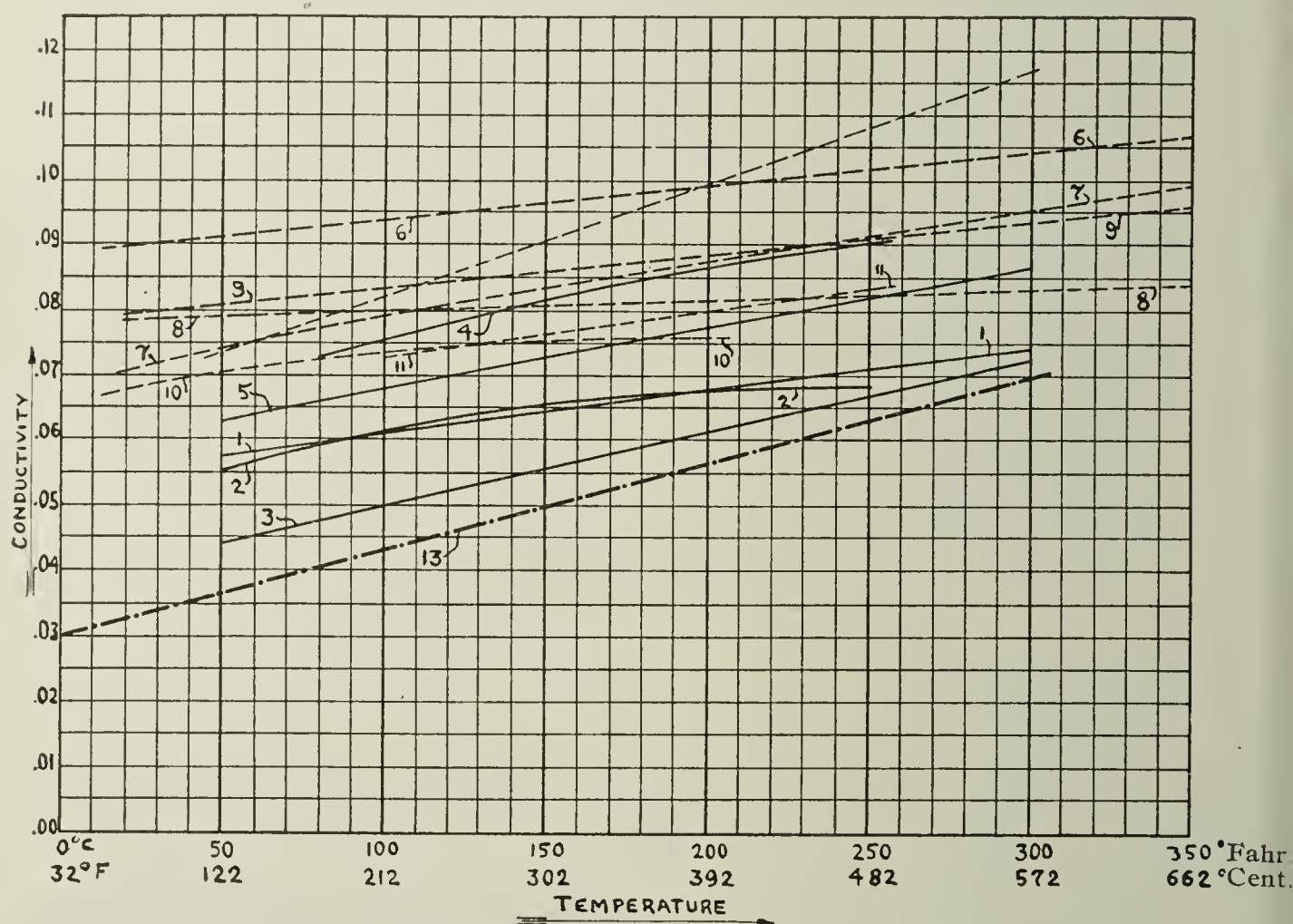


FIG. 5.—Conductivity of different materials [in calories per cubic meter per Centigrade-hour]. Curves 1 to 12 from "Forschungshefte" V.D.I. issue 228, p. 46; Curve 13 as per tests of the University of Munich [Prof. Dr. O. Knoblauch].

	Lbs./ cu. ft.
1. Asbestos-magnesia—loose mixture,	26.3
2. Asbestos-magnesia—loose mixture,	22.2
3. Asbestos-magnesia—loose mixture,	15.3
4. Asbestos-magnesia—cast slabs,	24.0
5. Asbestos-magnesia—cast slabs,	17.7
6. Asbestos-kieselguhr—loose mixture,	41.7
7. Asbestos-kieselguhr—loose mixture,	39.0
8. Asbestos-kieselguhr—loose mixture,	38.0
9. Asbestos-kieselguhr—loose mixture,	34.3
10. Asbestos-kieselguhr-cork—loose mixture,	20.9
11. Asbestos-kieselguhr-cork—loose mixture,	20.0
12. Kieselguhr—baked slab,	20.4
13. Glass wool—band form,	13.7

Speaking practically and taking the average for the different temperatures, glass wool insulation of about 20% less thickness will replace the best grade asbestos insulations; and glass wool of about one-half the thickness will replace mineral wool. The above figures apply to plane surfaces, in insulating pipes or curved surfaces. However, this difference in thick-

ness becomes wider and wider as the diameter decreases. Materials whose conductivities stand 1 to 2 for instance, and where double the thickness of the poorer would replace a single thickness of the better insulation on plane surfaces, would differ as much as 1 to 4, even 1 to 6 and more in thickness, to result in the same amount of insulation on a curved or round surface. The above example of 1 to 6 would apply to the extreme case of a $\frac{3}{4}$ -inch pipe, giving equal insulation with either $1\frac{5}{8}$ -inch glass wool insulation or 10 inches insulation of the material having a heat conductivity twice as big. The cause for this steadily growing advantage of the higher grade insulating material with the decreasing size of the pipes used, is due to the simple fact, that with the necessary added thickness for the poorer material, the outer circumference, or surface exposed to the surrounding air, also increases, resulting in an additional loss of heat, and requiring again more insulation. As insulation is used more on pipes than anywhere else, the value of a high grade insulating material is obvious.

Next of importance is the lightness of glass wool, whose weight per square foot of 1 inch thickness is only 1.14 lbs., as compared with 1.47 lbs. and more for the best asbestos-magnesia insulations.¹ What this light weight means, and especially for carriers, mainly ships, may be appreciated by considering that ships of the "Sebastopol" class (Russian battleship of the 1914 period), for which I happen to have the figures at hand, could save as much as 348,450 kilograms, or about 380 tons in weight by using glass wool insulation. These 380 tons, corresponding to the combined weight of about 4500 people, mean for this ship of 460 feet length, about 4 inches less draft, which again by reducing the resistance in the water results in a saving of coal.

Glass wool's mechanical strength and flexibility as compared with other insulating materials should not require scientific tests for anybody who ever handled or saw the materials. However it may be stated that 85% magnesia, asbestos claims a crushing strength of 100 lbs. per cubic inch,² which means 100 lbs. gradually applied and without shock, and though I have to admit that no laboratory figures are available on the crushing strength of glass wool, it may be comfortably tested by any heavyweight by simply stepping or jumping on it. This test will break a few of the longer fibers into shorter pieces, without impairing the insulating qualities.

Heat is being transmitted in three ways: by conduction, convection and radiation. Glass wool is the only insulator to meet all three. The first by its low conductivity, the second by the millions of dead air cells, preventing circulation, and the third by the reflection of the heat waves by each one of the silvery, smooth and shiny threads of glass.

¹ Johns Manville Catalog.

² E. R. Weidlein, *Chem. & Metal Eng.*, vol. 7.

As one cubic foot of glass wool weighs about 13.8 lbs. and as the average glass may weigh about 156 lbs. per cubic foot, about 90% of a given volume of glass wool is taken up by dead air cells.

Glass has been used long enough in chemical industries so that its favorable behavior in this respect does not require further comment. As we also know, it is resistant to moisture and air, and is non-hygroscopic.

Surprising, however, is the resistance of glass wool insulation to temperatures far over the melting temperature of glass, and where other high grade insulating materials deteriorate very quickly. Glass wool when so exposed will bake and even melt for about $\frac{1}{8}$ inch and sometimes $\frac{1}{4}$ inch right next to the overheated surface, and where it is in direct contact with the red hot iron. The fibers, however, behind this baked wall will remain unaffected and continue to give perfect and permanent insulation. This baking may begin at temperatures as low as 1200° to 1500°F, depending on the hardness of the glass used. A baking of this kind takes place for instance on the exhaust pipes of heavy oil engines, where this material has proved to be the only suitable one. These exhaust pipes are continuously red hot and burn out periodically. Whenever such a pipe had to be replaced, the glass wool was found to be in perfect condition and pliable with the exception of the thin baked layer right next to the pipe. How confident the manufacturers of this glass insulation are in this resistance to high temperatures is shown by the fact that they are now recommending it for the outside insulation of industrial furnaces for the melting of iron and metal.

The early methods of manufacturing glass wool were very crude and simple. The workman melted the tip of a glass rod over a gas flame and seized with another glass rod the forming drop, and threw it, with a quick twist of his hand, over a rotating drum, foot-operated by himself.

The first machines introduced, and those available when the War started, held a number of glass rods clamped in a horizontal position, feeding them gradually into a gas flame, at the same time turning them slowly, to provide for an even heating. (Fig. 6.) The work of the spinner merely consisted of drawing the forming drops over to the continuously revolving drum, by means of a glass rod. He had to renew the tearing threads in the same manner, and also stop the machine to renew rods that had been consumed, except for the short stub remaining inside the clamp.

The biggest advance in spinning was made by the very obvious and long delayed improvement of placing the revolving drum underneath the falling glass drops, thus doing away with the labor of continuously conveying and fastening glass drops to the drum. (Fig. 7.) This simple improvement proved to be so basic in the art, that very strong patents were obtained on this feature. The drops now fell automatically, by gravity, on to the drum, drawing the glass threads after them, and also renewing

the threads, when any of them broke. The drops themselves were thrown off by the centrifugal force of the turning drum, which retained only the pure and light wool. All the spinner had to do was to renew the glass rods, when consumed, and regulate the flames. One spinner was now able to watch three or four times the number of threads as before, with the drum ahead of him.

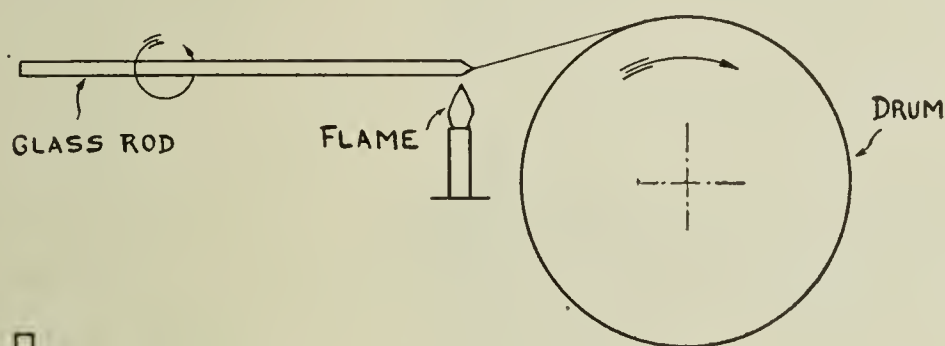


Fig. 6

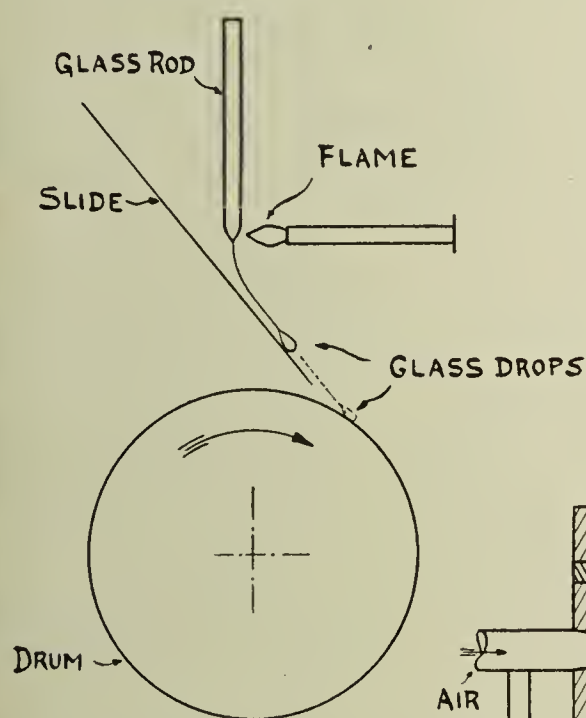


Fig. 7

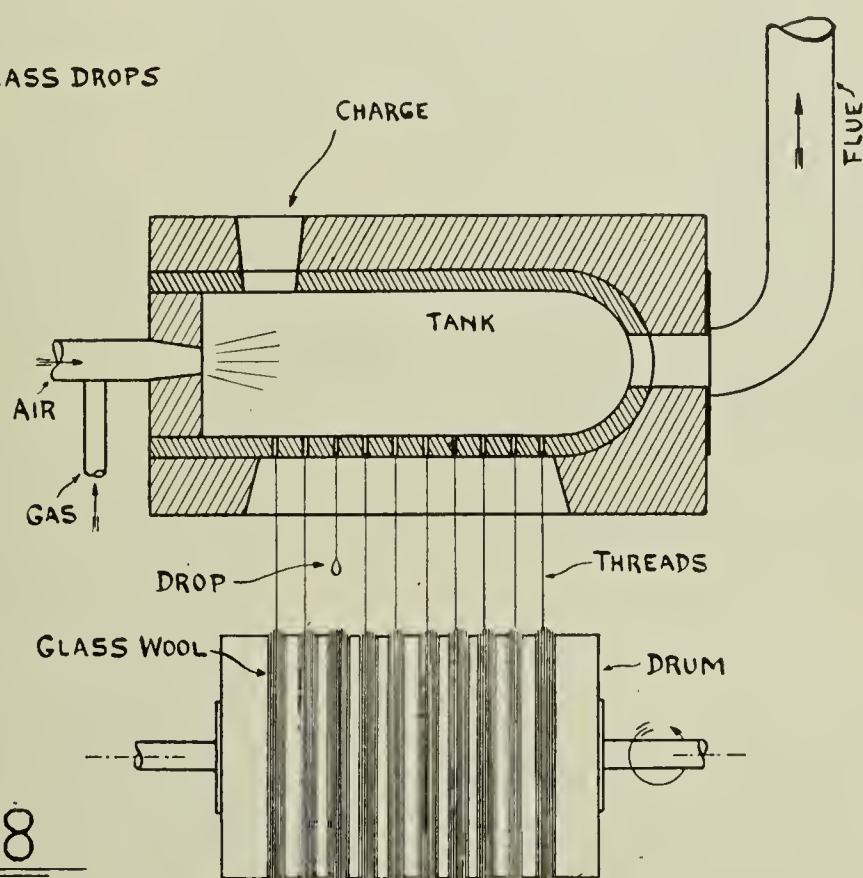


Fig. 8

As the cost of thin glass rods in Europe in pre-war times was about 7 cents per lb. whereas scrap glass had a market price of about $1\frac{1}{2}$ c., it was attempted very early to make glass wool directly from the molten glass, without the necessity to produce or buy glass rods first. Many methods were tried and abandoned, until at last the present way of using vats, containing the molten scrap glass, and provided with small openings at the bottom end was successful. From these openings the glass drops emerge, falling on to the drum below, and drawing the threads after them. (Fig. 8.)

Sometimes these openings are separately heated by an electric coil or gas flame, and sometimes air pressure is put above the molten mass. There are still smaller improvements possible no doubt, but these machines are working now and producing continuously, and the making of glass wool from rods has been abandoned entirely about a year. The factories though they can not be called large establishments according to our standards, are now producing an average of more than 8 lbs. of wool per employee-hour, mostly girl labor being employed.

When one drum is loaded with glass wool, it is stopped and the wool



FIG. 9.—“Carding.”

cut off and removed. The product is then carded and loosened up, a very simple process, but still performed by hand in a country where the necessity of economizing with labor has not quite reached our standards (Fig. 9.)

Quite manifold are the ways in which glass wool is applied as insulation. The most commonly used form is in the shape of bands about $\frac{3}{8}$ inch to $\frac{1}{2}$ inch in thickness and a width of from two to ten inches. This insulation weighs about three to four pounds per square yard. The loose and carded glass wool is put upon a table, mostly upon a sub-foundation of paper, burlap, or wire mesh, and run through sewing machines, which sew rows of

stitches about $1\frac{1}{2}$ inches to 2 inches apart into the wool sheet. The glass mattress is then run through cutting machines, cutting the bands to the desired width. In applying this insulation, these bands are simply wound spirally around the pipes in one or more layers. (Fig. 4.) The insulation may be finished off on the outside by bandaging and painting in customary manner, if so desired. When larger surfaces and not pipes are to be insulated by this method, the mattresses are not cut into bands but trimmed to the size required. (Fig. 10.)

Larger pipe lines and objects are often insulated by first surrounding them with coarse wire mesh, distant from the object, to represent the outline of the finished insulation. The glass wool is then simply stuffed in between the wire mesh and the body to be insulated. (Fig. 11.)

The highest grade insulation, and the one used exclusively on locomotives, boilers and other objects, where the insulation has to be removed at intervals to make inspection and repairs on the machinery or boilers, is made in the following way. From a drawing or sketch two templates are cut out of wire mesh of the weave of narrow chicken wire. Next these two templates reach an operator, to whom also a certain amount of glass wool, figured in so many pounds to the square inch, is allotted. In the above process about 3 to $5\frac{1}{2}$ lbs. per square yard are figured, depending on the quality of insulation desired. The girl distributes the glass wool received evenly over one of the templates, covers the whole with the other template, and crimps the edges. On large surfaces she may crimp a few wire staples through the center. The mattress is now ready to be fastened to the object to be insulated, can be removed whenever required, and will stand all kinds of rough usage. (Figs. 2 and 3.)

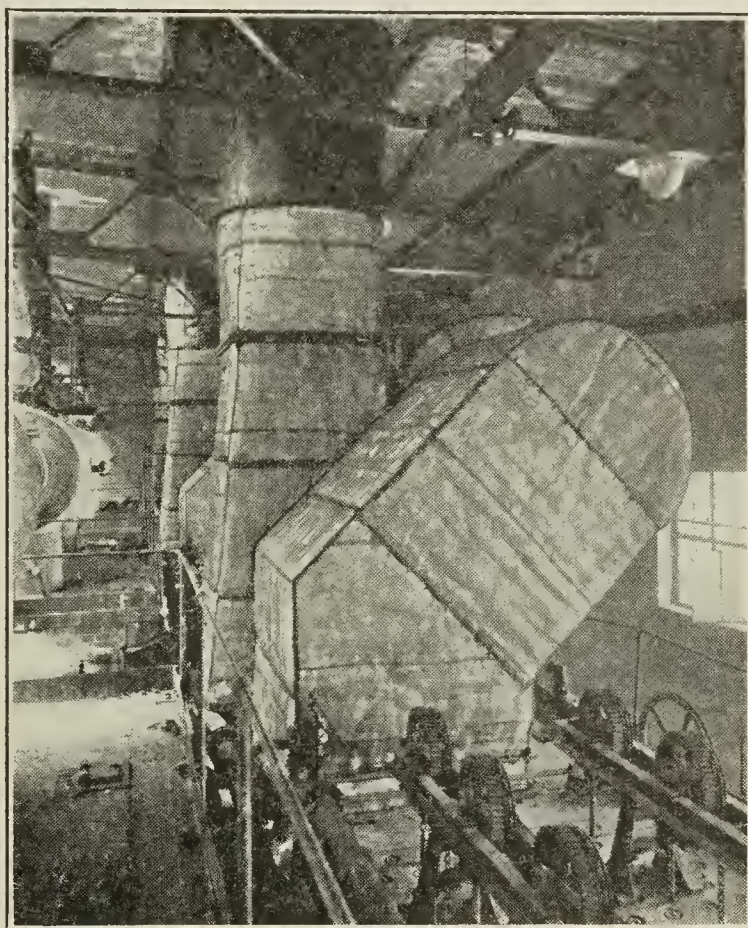


FIG. 10.—Sewed mattresses.

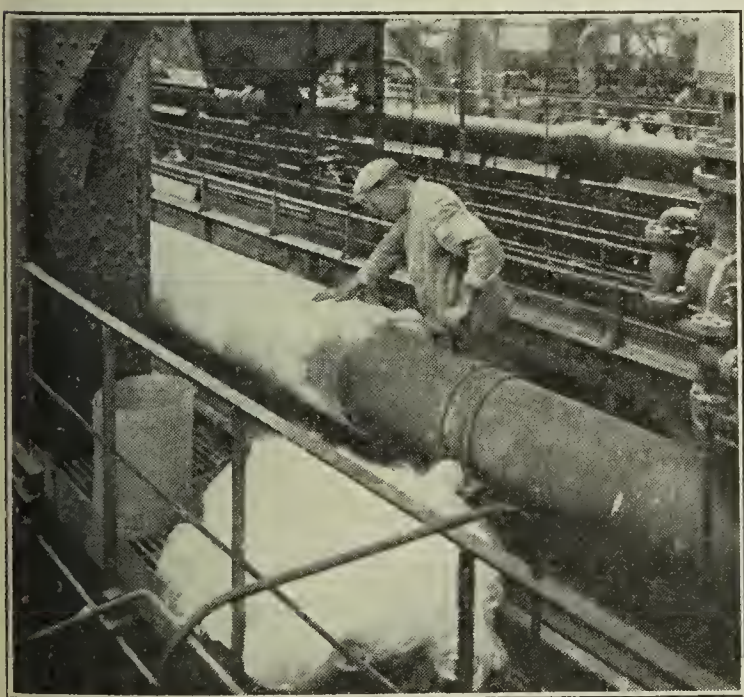


FIG. 11.—“Stuffing” glass wool.

Glass wool is now being manufactured in considerable quantities and economically. The German factories in Hamburg, which have enlarged to several times their original size, have been working on three 8-hour shifts since 1918. A large new factory for the production of glass wool is under construction in Dresden, Saxony, where every furnace will feed three vats of two hundred openings each. It is estimated from present production figures that about 6500 lbs. of wool would be produced in 24 hours

working time. The help required would be two spinners, one melter and one helper per furnace, which would result in an output of almost 70 lbs. per man per hour.

It would be preposterous for me as a layman in glass generally, to attempt estimating the American costs for the manufacture of glass wool. The more so as the German costs, with the constant rise and fall of the mark, and the daily changing wages, can hardly be used as a base. The fact is that the German manufacturers themselves can not establish their present costs, nor can it be established for them by any accounting method in captivity. The amount of labor required to produce a pound of wool has been stated above. The fuel consumption is 32 cubic feet of artificial gas per one pound of glass wool. The wastage of material in the shape of drops, etc., amounts to about 10%, which waste is remelted in the next load or in a smaller furnace. The manufacturers of glass wool, setting their material as the most important item at 100 units, figure their labor at 40 units, and their overhead again at 40 units of their total cost. Translated into our usage this means 100% overhead, based on labor. Faced by the impossibility of establishing his exact cost, the German manufacturer plays safe by fixing his selling price in foreign exchange, preferably *dollars*, and based on this dollar price makes his quotations in marks, according to the exchange value on the day of sale, or still better, the day of delivery. Glass wool insulation is selling for 12 cents per lb. in competition with the highest grade imported insulations. From what I have seen and heard I would reservedly place the manufacturing cost today at about $2\frac{1}{2}$ to $3\frac{1}{2}$ cents per pound.

Several patents were obtained during the development of the manifold processes and machines. All thinkable possibilities were tried, out of which the present machines finally crystallized. This process of producing glass wool directly from a molten mass of glass is new, and has been well protected in all civilized countries. The number of the American patent covering this feature is 1,427,014.

European glass manufacture of the type produced by machinery has never been able to gain a strong foothold in our country. As far as glass wool is concerned, the German manufacturers realize that introducing a new line like theirs into the vast field of heat insulation could not be done in a small way in U. S. A., and establishing branches, advertising, and paying for these and other incidentals of pioneering in foreign currency, constitutes an utter impossibility for them.

Born under the pressure of the past War, glass wool heat insulation is one of the very few inventions and substitutes of war times, which have proved valuable, and therefore have survived peace. Now that glass wool is available in quantities and cheaply, new fields besides insulation will probably be opened to this product as the years go by. But as far as insulation is concerned, there is no doubt to my mind, from what I have seen, heard and investigated as an engineer, that glass wool is the coming heat insulation, and coming fast.

COPPER REDS FOR THE AMATEUR

BY PAUL E. COX

ABSTRACT

A brief review of the history of the production of such wares is given. Methods are described that can be used by the person having china painter's kiln. This paper is presented to encourage the amateur to make use of simple equipment for the production of decorated wares in which a satisfactory ceramic red can be produced.

Introduction

Joseph F. Meyer, Alsatian Frenchman, son of a French peasant potter, for almost thirty years with Newcomb Pottery, and a clever craftsman, had for his heritage the recipes and processes of his country. From the material thus at hand and from his reading of the literature of his native country he developed a simple process of making copper reds which for some years were a part of the offerings of Newcomb Pottery. The jury at the St. Louis Exposition awarded a gold medal to this self-taught French peasant. A process similar to Mr. Meyer's for copper red effects is here described.

Any book that deals with the lusters produced by the Italian and Spanish faience potters, or the Turkish or Persian wares will suggest the process. The technique is elementary in the extreme. Certainly the French authorities on ceramic processes describe the process very well, but the application to the modern amateur china painter's kiln has not been made.

The Materials Needed

The Glaze.—The glazes of most whitewares are too refractory to admit of copper red staining. It requires a soft or easily softened glaze such as is used in the manufacture of jardiniers and the numerous little bowls and vases that are so strongly refractive or reflective of light. These are usually inexpensive. Matt glazes will yield copper reds but they are not very often interesting. Many little Japanese bowls and vases likewise are suitable for work of this sort.

The Equipment and Supplies.—A china painter's kiln, or any kiln in which a good red heat can be developed, will serve the purpose very well. A glass slab, a glass muller, some brushes, a little kaolin or ball clay or any other kind of clay, perhaps a little fine white sand or better some finely ground calcined clay, and either copper carbonate or copper oxide and some pitch pine knots make up the list of needed supplies.

The Applying of the Copper

On the glass slab mix a paste of clay with water, using the muller to grind the paste smooth. Add the copper oxide or copper carbonate in such amount as satisfies the worker that some copper compound will be

all through the mixture. It is safe to say that 10% will more than suffice. When the mixture is well blended apply in a good thick coat and allow the treated pieces to dry well before putting them into the kiln. The thickness of the coat should be roughly about $\frac{1}{16}$ of an inch.

It will be found that such a mixture will crack like the mud drying in a puddle. This can be overcome by using calcined clay, flint, sand, or similar non-plastic material. However some accidental effects are had from the peeling away of the coating that are at times desirable, so that the experimenter must decide what is desirable according to the end in view. A very little raw clay will serve to make sticky a very large amount of non-plastic material and so the control is at hand by varying the amounts of clay and non-plastic.

Fire-clay shelves or slabs should be procured from the dealer that furnished the kiln, with which to set up a muffle or built-up chamber in the kiln, so that the tubes and kiln walls will not absorb copper oxide vapors and later give it off again on white porcelains. The cost of this muffle protection will not be great, it facilitates the setting; and in every way the need justifies the expense.

The Firing of the Kiln

It will be assumed that the wares are placed on fire-clay shelves and that the kiln is ready to fire. The firing is done exactly as it would be done for painted china, except that when large pieces are present, they will be thicker bodied than porcelain usually is, so that the precaution must be observed of heating up more slowly. The kiln should be brought to a good red. Since the composition of the glaze will be unknown, the exact temperature must be determined by experiment. This is judged from two considerations. The kiln must be hot enough to make volatile the copper and to soften slightly the glaze of the wares. It must not be hot enough to soften the glaze sufficiently to cause the clay vehicle to stick to the ware. Obviously this point must be determined by test, but a china painter will not find this hard to determine, for it is within the limits of temperatures common to that craft.

When the maximum temperature desired is reached this must be maintained for an hour at least while the copper oxide is vaporized and deposited in the glaze and then changed from the green state to the red. Of course, all three processes are going on at once.

While the temperature is being kept at this maximum, pine knots are added one or two at a time by opening the kiln door and placing the knots on the floor of the kiln in a place reserved for them. This requires quickness of movement on the part of the experimenter to conserve the kiln heat. A pair of asbestos mittens will be helpful and a pair of suitable tongs will of course be needed. The knots will break into flame at once

and with the kiln door quickly closed a black smoke will fill the muffle chamber. This black smoke in the muffle at the maximum temperature must be maintained for an hour or more. The kiln then should be allowed to cool but the smoky atmosphere in the muffle should be maintained until a decided lowering of temperature is observed, which can be judged by the comparative dullness of the red of the heated objects.

Joseph F. Meyer used a small hand bellows to force the billowing smoke clouds about in the ware chamber, and so make more even the reducing action.

It should be noted in passing that Mr. Meyer did not use the china painter's kiln but a kiln similar in idea in which he burned coal and which is the type of kiln used so largely in France as a decorator's oven.

The writer has found that if the piece of ware is enclosed in a reasonably tight and reasonably close fitting clay vessel, which has been coated with the copper bearing paste and the same treatment is given, the red is produced without the trouble of washing away the coating after the firing. That is, there is no paste applied to the piece of ware that is being treated. Results are not so interesting however.

The Treatment after Firing

When the kiln is opened the next day, if everything has gone well, it will be found that the clay coating can be scrubbed off with water, and that the glaze has taken a more or less regular transparent red, and in places a luster. If the reduction has progressed far enough it will be found that copper appears as a metallic film. The desirable result is of course to have the red in abundance.

Blistering of the Glaze

Clément Massier, working in France, has produced some pieces which museums and collectors value, in which the glaze is much blistered. This results from firing at a higher temperature, and also some glazes are prone to blister under the treatment. Those who develop their own glazes can overcome this blistering by developing a harder glaze, while those who have to depend on a purchased pottery can but hunt until they find that which will work well.

Conventional Designs in Copper Red

Massier likewise produced wares with the red placed where he wanted it. For example, he had designs with a conventional frog whose eye was a devilish red. If the paste is placed on the eye of the frog and at no other place that will be the only red place on the ware.

Use of Colored Glazes

It will be found that wares with blue in the glazes, and most colors other than green, will yield the most interesting results. However colorless glazes quite often give fine results.

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Correction

Wilson, R. E., and Hall F. P., "The Measurement of the Plasticity of Clay Slips," *Journal of the American Ceramic Society*, 5 [12], 920 (1922), Fig. 3: The ordinates should be divided by 100; *Ibid.*, 924, Fig. 5: $\frac{W}{C} = 12.0$ for Bentonite, not $\frac{W}{C} = 1.20$; *Ibid.*, 925, Fig. 6: $(H^+) = 10^{-7}$, not $(H^+) = 10^{-10}$.

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No. 6

ORIGINAL PAPERS

THE RELATIVE ACTION OF ACIDS ON ENAMEL—V¹

BY EMERSON P. POSTE

ABSTRACT

The work of the former Committee on Standardization of Tests is the starting point
for the work covered in this paper. The action of citric acid on different types of enamels
studied. The time required to produce first etching of cooking ware enamels with
10% acid is investigated. The above lead to the conclusion that commercial cooking
ware enamels as a whole are readily etched by 15% citric acid and the degree of etching
is not necessarily proportional to the time of action. The use of 1% acetic acid and
so the use of a "spot" test are investigated, including tests on commercial ware. The
work as a whole brings out certain weaknesses of the possible methods of testing but does
not result in the establishment of a satisfactory test.

Introduction

Previous volumes of the *Journal*² contain records of work done towards
the establishing of a reliable quantitative test for the acid resistance of
enamels. The importance of a standard solution easily made without
the use of laboratory facilities was brought out and a solution of 6 ounces
citric acid in one quart of water was selected as a possible standard.
It was shown that the slight variations in strength which might come in

¹ Presented before the Enamel Division, Pittsburgh Meeting, February, 1923.

² E. P. Poste, "The Relative Action of Acids on Enamel, III," *Jour. Amer. Ceram.*
Soc., 2 [1], 32-43(1919); *ibid.*, IV, 3 [7], 560-7 (1920).

with solutions made by the average druggist were of negligible amount in terms of action on enamel. Efforts to determine definitely the amount of action on an enamel surface included the possible staining of the etched surface by an organic dye and the possible use of lamp black-vaseline smear as an indicator.

During the past year efforts have been made to determine whether former ideas could be brought to a successful conclusion and the burden of the present record is the information bearing on this point together with data regarding certain other proposed tests which came to the attention of the Committee.

Further Work on Citric Acid

The former work on citric acid had involved a rather limited number of enamels. The question arose as to whether all enamels would have the same general characteristics in terms of resistance to citric acid. To determine this point frit tests¹ were run on three enamels in addition to those previously reported.² The results can be easily noted by reference to Fig. 1. The curves "White—IV-A-1" and "White—IV-A-2" are reproduced from the previous record² as a matter of comparison. The

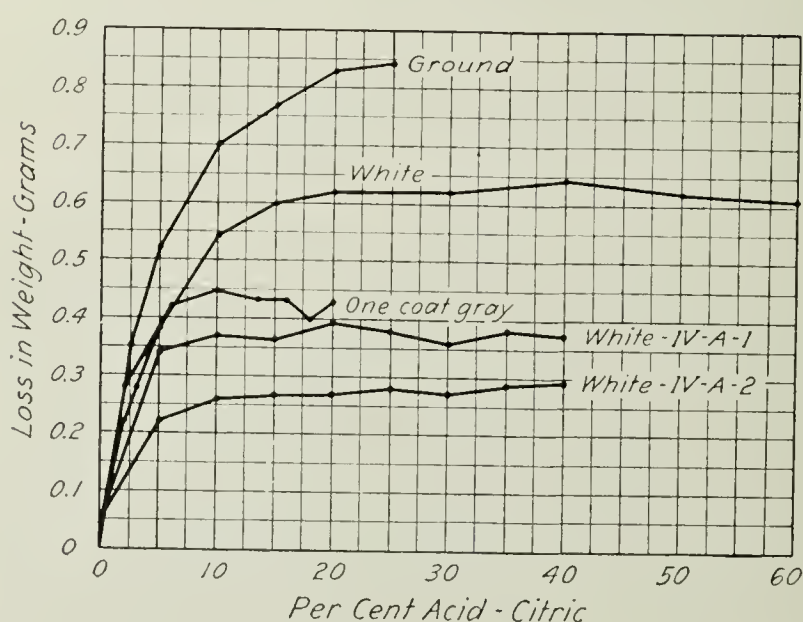


FIG. 1.

This may be partially due to depletion of acid in the solution—this test is not recommended for two-gram samples and 100 cc. of solution in cases where the loss in weight goes much above 0.5 gram. In such cases the amount of solution should be increased or the weight of sample decreased.

The second point to be investigated was with reference to the time required to produce first etching using the black smear as an indicator. This can be best presented by quoting from one of the reports covering actual test.

¹ *Trans. Amer. Ceram. Soc.*, **17**, 138 (1915).

² E. P. Poste, *Jour. Amer. Ceram. Soc.*, **3** [7], 561 (1920).

The following plan was adopted for showing the effects of different times of action on a single piece of ware. Taking a pan of about one quart capacity, 100 cc. of the acid solution were placed in the dish and allowed to stand one hour. At that time 100 cc. more were added and the same continued at intervals of 90, 105, 112 and 116 minutes. At 120 minutes the solution was poured out and the dish rinsed. When dry the successive rings of etching from top down showed the effect of 4, 8, 15, 30, 60, and 120 minutes action.....

Samples of eight different makes of white ware were tested in this manner with 15% citric acid at room temperature, 80–90°F. These included a very highly resistant white and a very soft white..... All were examined after streaking with a mixture of lamp black and vaseline. The results of the observations are as follows:

No. 1—No visible action after two hours.

No. 2—Same, but shows slight action on small parallel patches about one-half inch long and one-sixteenth inch wide after two hours.

No. 3—Etching was visible in four minutes. After two hours the etching was not strong and the gloss was not lost.

No. 4—Etching was visible in eight minutes. After two hours the etching was not serious.

No. 5—Shows etching in four minutes. Not bad in two hours but worse than No. 3.

No. 6—A German ware. About the same as No. 3.

No. 7—Etched strongly in four minutes.

No. 8—Etched strongly in four minutes. Disintegrated in two hours. Shows etching where solution was poured out, not in contact more than one second.

In commenting on the above the member of the present committee doing this work says:

From the above it appears.....that it is not practical to base a test on the time required for the first appearance of etching since the latter is not related to the extent of etching on longer treatment. 'Two hours' treatment serves to differentiate sharply between the different grades of enamel by direct comparison one with the other.¹

Further work along this line was done using two commercial enamels designed for two classes of work; the first for the dairy trade, the most severe acid condition involved being about one per cent lactic, the second for the canning trade involving a large variety of combinations of organic acids at rather low concentrations. Both enamels are commercially successful in the respective fields. Using 15% citric acid at room temperatures an exposure of one hour for the dairy enamel produced an etching visible without the use of the smear, while a half hour exposure produced practically as severe results. The canning enamel gave an etching on one-half hour exposure that was visible without the smear, on one hour an etching not seen by the unaided eye but easily seen by aid of the smear, and a slight etching as indicated by the smear on one-half hour exposure. From these and other studies it became evident that citric acid of the chosen strength would throw out enamels known to be satisfactory for

¹ H. F. Staley, "Some Relations of Composition to Solubility of Enamels in Acids," *Jour. Amer. Ceram. Soc.*, 4 [9], 711 (1921).

kitchen use if the first appearance of etching as detected by the smear was to be taken as the basis of judgment. It was also evident that etching as detected by this method was not proportional to time of exposure.

Proposed Bureau of Standards Test

At this particular juncture the attention of the Committee was called to the tentative test which had been recently suggested by the Bureau of Standards. This test is essentially as follows:—

A solution of one per cent glacial acetic acid and 99% distilled water by volume at a temperature of 60° to 70°F is placed in the article and removed hourly. The piece is examined for loss of gloss or etching—either of which is considered as indicating failure of the enamel.

In studying the tentative test of the Bureau of Standards with reference to a standard test for the SOCIETY the Committee considered several points. The first was that of the reliability of the proposed solution with reference to strength.

One Per Cent Acetic Acid as a Standard Solution

It was anticipated that the stock of glacial acetic acid that might be found on the average drug store shelf would vary in strength, and that the average druggist might have some difficulty in making up a solution of exactly the desired strength. To determine these points samples of glacial acetic acid obtained from three drug stores were analyzed, as well as acid from a stock bottle in the laboratory. Dilute solutions were also made up in accordance with the specifications of the test. In the Laboratory

ACCURACY OF "1% BY VOLUME GLACIAL ACETIC ACID SOLUTION"

Source of acid	Per cent by weight stock	Per cent by weight dilute	Remarks
A	99.1	1.13	Rough method
		1.06	Accurate method
B	100.0	0.82	Glass stoppered bottle
C	100.0	0.33	Glass stoppered bottle
D	97.1	0.88	Cork stoppered bottle
E	99.0	1.05	

A—Laboratory stock.

B, C, D—Local drug stores.

E—To be expected from U. S. P. specifications.

laboratory two methods were followed: one using ordinary graduated cylinders and the other using a volumetric flask and dispensing the acid from a burette. The effort was made to get samples from five stores. Two of these did not have glacial acetic acid. One of the druggists furnishing solution did not seem to know how to go about the dilution of the acid. The results of these efforts in terms of content of acetic acid by weight are given in

the preceding table. It should be kept in mind that the U. S. P. specifications for glacial acetic acid state that it is "a liquid containing not less than 99% of $C_2H_4O_2$ or CH_3COOH ." It further states that it should be kept in a glass stoppered bottle. On the basis of a 99% solution by weight as the starting point a 1% solution by volume should contain 1.05% by weight.

From the above it seems that it might be difficult for the enameler not having laboratory service available to get, under the given specifications, acid of accurate strength.

The next point to be investigated was the seriousness of the above irregularities in the strength of acetic acid in terms of action on enamel. A series of frit tests was run using an enamel considered reasonably similar in acid resistance to the average cooking ware grade. The results are seen in Fig. 2. At "A" is indicated the action of a 1% solution, and at "B," "C" and "D" the action

of the corresponding strengths as shown in the Table. It may be concluded that variations of $1/4\%$ in either direction would not have a serious effect on this particular frit. But it is possible that the break in the curve would come at some other point with other enamels, in which case a solution of .75% strength might give

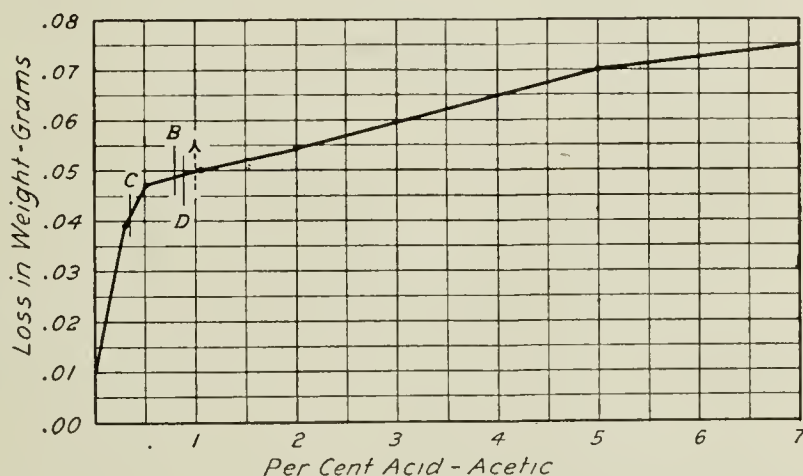


FIG. 2.

quite different results from a solution of 1.0% strength. It is obvious that the error involved in "C" is unreasonable. It certainly is serious enough to affect materially the rate of action.

With further reference to the choice of an acid another line was followed out. It had been concluded that 15% citric acid was too strong but that citric could be made up to accurate strength by the average druggist. It was also evident that 1% acetic was of about the proper strength but was possibly subject to serious irregularities in strength as made up by the druggist. How about a citric solution of the same rate of action on enamel as 1% acetic? To throw light on this point a series of frit tests was run using weak citric solutions on the same frit involved in Fig. 2. It was concluded from this that 0.15% citric has about the same rate of action as 1% acetic. The use of this acid will be discussed later.

Spot Test

Another method of testing came to the notice of the Committee. It was referred to as a "one minute spot test" and was described as follows:

.....place a drop of the acid solution on a horizontal surface of the piece, allow it to remain one minute, then wipe with a damp sponge and rub lightly with a dry towel. If the enamel has been acted upon a reduction in specular reflection is easily observed at the spot where the acid was applied. By this test 1% citric acid affects most of the enameled cooking utensils on the market and even 1% acetic acid shows slight diminution in specular reflection on some of the high priced ware. This test can be made approximately quantitative by determining the strength of acid which will just affect the surface of the enamel. For a simple test to be used outside the laboratory for acceptance or rejection of ware, a standard strength acid can be used but it will be necessary to decide upon a low percentage if rejection of most of the ware on the market is to be avoided.

Tests of Commercial Ware

As a matter of comparison of the above three methods of testing a number of representative pieces of commercial ware were obtained from local stores. They were as follows:—

- No. 1—Good looking white inside and out.
- No. 2—Good looking white inside and out.
- No. 3—Good looking white inside and out.
- No. 4—Fair white inside, mottled blue outside.
- No. 5—Poor white inside, mottled blue outside.
- No. 6—Fair white inside, mottled blue outside.
- No. 7—Light blue inside and out.
- No. 8—Mottled brown and white.
- No. 9—Good granite.
- No. 10—Poor granite.
- No. 11—Fair granite.

The three methods of testing were designated by letter as follows:

- A—1% acetic acid—1½ hours.
- B—0.15% citric acid—1½ hours.
- C—One minute spot test.

In the testing, the dishes were tipped differently in A and B so as to keep the areas in contact with acid separate, also saving unexposed areas for use in C.

After exposure to the acetic acid the surfaces were cleaned and examined visually. In general they were as follows:

- No. 1—Very definite action.
- No. 2—About like 1.
- No. 3—Possibly a little worse than 1 and 2.
- No. 4—About like 1 and 2.
- No. 5—About like 1 and 2.
- No. 6—Definite action but not as bad as 1 and 2.
- No. 7—About like 6.
- No. 8—No visible action.
- No. 9—Very slight action.
- No. 10—Slight action but more definite than 9.

No. 11—Edge of exposed area could be faintly seen but no actual loss of gloss could be noted.

Three different persons were asked to place the various pieces in their order of decreasing acid resistance. The results were as follows:

White Inside 6-5-4-2-1-3
 6-5-1-3-4-2 Average 6-5-1-(4-2)-3
 6-5-2-1-4-3

Colored 8-7-11-9-10
 8-11-9-10-7 Average 8-11-7-9-10
 8-11-7-9-10

Entire Lot 8-6-11-7-9-5-10-4-2-1-3
 8-11-9-6-7-10-5-4-1-3-2 Average 8-11-(6-7-9)-10-5-4-2-1-3
 8-11-7-9-10-6-5-2-4-1-3

In like manner the dishes were tested with the 0.15% citric acid. In general the action of the citric had been more severe than the previous acetic. The observations were as follows:

No. 1—Gloss nearly gone.
 No. 2—Dull. Gloss practically gone.
 No. 3—Dull.
 No. 4—Dull.
 No. 5—Gloss nearly gone.
 No. 6—Very slight action.
 No. 7—Very marked action. Very dull.
 No. 8—Trace of action. Less than No. 6.
 No. 9—Definite action. Still somewhat glossy.
 No. 10—Dull.
 No. 11—Gloss partly gone.

The pieces were placed in order of decreasing acid resistance by three parties as before with the following results:

White Inside 6-5-1-4-2-3
 6-5-4-2-1-3 Average 6-5-4-1-2-3
 6-5-4-1-2-3

Colored 8-9-11-7-10
 8-9-11-7-10 Average 8-9-11-7-10
 8-11-9-7-10

Entire Lot 8-6-11-9-5-2-1-4-7-10-3
 8-9-11-6-5-4-7-10-2-1-3 Average 8-6-11-9-5-7-4-(10-2)-1-3
 8-6-11-9-7-5-10-4-1-2-3

The spot test was applied to the sample pieces of ware using two different acids: 1% acetic, and 1% citric. The results were judged in terms of four classifications—no spot, slight spot, definite spot and dull spot. The slight spots could only be seen under the best of reflected light; the definite spots without particular effort and the dull spots without the use of strong reflected light at all. The results are tabulated:

Number	1% Citric	1% Acetic
1	Dull	No
2	Slight	No
3	Definite	No
4	Slight	No
5	Definite	Slight
6	Slight	No
7	Definite	No
8	No	No
9	No	No
10	No	No
11	Slight	No

Classification in terms of decreasing acid resistance as suggested by this test results as follows:

(8-9-10)-(2-4-6-11)-(3-5-7)-1

As a matter of comparison the various sets of classifications will be presented together:

1% acetic acid—8-11-(6-7-9)-10-5-4-2-1-3

.15% citric—8-6-11-9-5-7-4(10-2)-1-3

1% citric spot—(8-9-10)-(2-4-6-11)-(3-5-7)-1

These three tests agree in designating No. 8 as the best enamel as to acid resistance, although in the spot test two other enamels were classed with it which were not next to it in the other tests. The first two tests agree in allowing No. 8 to pass, and placing next or near to it the same numbers. They also agree in naming No. 3 as the poorest with numbers 1 and 2 next in order. The other samples vary in exact order but appear in the same general grouping in both cases.

With reference to the effort to substitute 0.15% citric acid for 1% by volume acetic it has been noted that in the above tests on commercial ware the citric acid acted more severely than the acetic, though the relative action on the different enamels was in about the same order. Although citric acid is more uniform as found in stock there would be definite objections to depending on a solution as weak as or weaker than 0.15% as a standard solution. Slight errors here would make marked differences in rate of action as the curve of action against concentration is very steep at this point. The amount of acid involved in making up relatively small batches of acid would be small and subject to error. So the work done would not seem to vindicate as a substitute for 1% acetic acid, citric acid of the same rate of action on enamel. It would probably result in less error to use the 1% acetic taking special precautions to see that it was made up accurately from stock of the proper composition.

Summary

In thus rather roughly reviewing the work of the Committee we have placed on record various points that may add to the general knowledge

regarding the action of acids on enamel. We have brought out further information with reference to the action of citric acid on different enamels. Previous investigators have been checked in their findings that acid action on enamel surfaces is not necessarily proportional to time and this suggested in this case the present impracticability of attempting to make use of a definite quantitative basis for acid action. We have reviewed the Bureau of Standards tentative test and while we have found certain points of criticism with regard to the acid named therein, we have failed to arrive at a satisfactory substitute. We have further carried out certain tests on commercial ware including a spot test that, without doubt, would be of value as a means of quick results in the hands of one experienced in its use.

NOTE: We wish to acknowledge the hearty coöperation of the members of the Committee, R. D. Cooke, H. N. Cox and L. J. Frost, for the part they have had in the experimental work and suggestions in regard thereto.

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A RAPID MEANS FOR THE DETERMINATION OF QUARTZ CONTENT OF FELDSPAR¹

BY M. C. BOOZE AND A. A. KLEIN

ABSTRACT

The quartz content is determined by making a rapid fusion of the feldspar without dissolving an appreciable amount of the quartz, crushing the fused mass, immersing a portion of it in a liquid of the proper index of refraction and comparing the visible quartz with standard samples containing known quantities of quartz. A difference of 5 per cent in quartz content can readily be detected. The fusion and optical examination can be made in two hours and does not require a knowledge of microscopy.

The commercial grades of feldspar as milled by practically all producers today contain considerable quantities of quartz. The removal of even a large part of the quartz is so difficult that we cannot expect to obtain a product with less than 10% present and in many cases the content will be as high as 30 or 35%.

This condition has probably been reached in recent years, the producer having worked out his purer deposits and is now being forced to turn to the more impure ones. Except in rare cases the quartz crystals are so intermingled with those of feldspar that complete removal of the former is practically impossible.

The determination of the quartz content by chemical analysis requires too much time to be practical where it is desirable to test shipments before unloading and is only satisfactory where decomposition products or accessory minerals other than quartz are absent.

The effect of the quartz is largely to dilute the feldspar. While it does affect the softening point, a softening point determination is not sufficiently accurate for the determination of the amount of quartz present nor the variation in amount between shipments.

Since feldspar is largely used in ceramic bodies to which free silica is intentionally added, the presence of quartz is usually not objectionable. The variation in quartz content, however, is equivalent to changes in composition of the body and so should be avoided.

The method which has been devised for the determination of the amount of quartz depends, for its success, upon the difference in optical properties between feldspar glass, and quartz. The optical constants of the crystalline alkali feldspars and quartz may be so alike that the two are difficult of quantitative separation microscopically. Since there is a considerable difference between the temperatures at which feldspar and quartz lose their crystallinity, it is easily possible to fuse the one without affecting the physical state of the other. When this is accomplished it becomes an easy matter to distinguish between them microscopically.

¹ Presented before the Whiteware Division, Pittsburgh Meeting, February, 1923.

In the practical application of the method therefore, a sample of the feldspar containing quartz is heated rapidly to a point where the feldspar becomes a glass without appreciably affecting the quartz either by fusion or by solution. The fusion when cold is crushed and a portion of the powder immersed in a liquid or resin of the proper index of refraction, *e. g.*, clove oil, ethylene bromide or Canada balsam and an estimate made of the relative amounts of feldspar glass and quartz.

In order that more accurate determinations might be made, a quantity of pure feldspar was obtained by careful selection and fusions were made of mixtures of this feldspar, with known quantities of quartz. By comparison with the known samples the quantities of quartz in unknown samples may be readily and accurately determined.

In the successful application of this method it is of course necessary to completely fuse the feldspar without dissolving an appreciable quantity of quartz. Time required for the test is also an important factor where tests are run on incoming shipments. To determine the limits for the proper heat treatment, fusions were made at cones 9, 10, 11 and 12, each being made in a pot furnace using city gas and air at 12 pounds pressure. The interior diameter of the furnace was approximately 8" x 10" high. In some cases the fusions were in the shape of standard cones and in other cases were made in alundum crucibles approximately 1 inch in diameter by 1½ inches high.

The data on these runs are as follows:

Cone 9 tip touching cone 10 started in 2-hour burn with no soak. New Hampshire feldspar contained 10 to 15% of crystalline feldspar. Maine feldspar also indicated considerable quantities of unmelted feldspar. In neither case was there a noticeable amount of quartz solution.

Index of refraction of glass from New Hampshire feldspar = $1.486 \pm .001$.

Index of refraction of glass from Maine feldspar = $1.488 \pm .001$.

Cone 9 tip touching in 1¼ hours with a 15-minute soak. New Hampshire feldspar indicated 10% of quartz with no quartz solution. From 3 to 5% of crystalline feldspar was present. Maine feldspar indicated 30% of quartz. About 5% of crystalline feldspar was present.

Cone 10 tip touching in 1¾ hours with a 15-minute soak. New Hampshire feldspar showed a trace of crystalline feldspar but there was none evident in Maine feldspar.

There was no evidence of quartz solution.

Index of refraction of glass from New Hampshire feldspar = $1.486 \pm .001$.

Index of refraction of glass from Maine feldspar = $1.488 \pm .001$.

Cone 11 tip touching in 1½ hours and soaked for 15 minutes. There was no crystalline feldspar present in either the New Hampshire or Maine samples nor a noticeable amount of quartz solution.

Index of refraction of glass from New Hampshire feldspar = $1.486 \pm .001$.

Index of refraction of glass from Maine feldspar = $1.488 \pm .001$.

Cone 11 tip touching in 1½ hours and soaked for 30 minutes. The data here were the same as in the previous run, there being no measurable quartz solution from the longer soak.

Index of refraction of glass from New Hampshire feldspar = $1.486 \pm .001$.

Index of refraction of glass from Maine feldspar = $1.488 \pm .001$.

Cone 12 tip touching in $1\frac{3}{4}$ hours and soaked for 15 minutes. The data here indicated no more quartz solution than for the lower heat treatments. There was no crystalline feldspar present in either case.

Index of refraction of glass from New Hampshire feldspar = $1.486 \pm .001$.

Index of refraction of glass from Maine feldspar = $1.488 \pm .001$.

It is evident that cone 11 is the minimum for bringing about complete fusion in a heat treatment of approximately two hours. The length of soak determines the completeness of the fusion as does also the size of the sample. Crystalline feldspar has been observed when cone 12 was put down flat in one hour with no soak. A crucible larger than 1 inch to $1\frac{1}{4}$ inches in diameter should not be used and the amount of charge should not be over 20 grams. A heat treatment corresponding to cone 12, down in $1\frac{1}{2}$ hours, with a 15-minute soak is recommended as being the least liable to give erroneous results.

This heat treatment will suffice for a feldspar high in potash as well as one containing approximately equal percentages of potash and soda.

The following analyses give the compositions of the Maine and New Hampshire feldspar used, the former indicating 30% of quartz and the latter 10% by the method of fusion and microscopic examination:

	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	TiO ₂	CaO	MgO	Loss on ignition	Na ₂ O	K ₂ O	Total
New										
Hampshire	17.33	Trace	66.69	Trace	Trace	None	0.21	2.98	12.01	99.22
Maine	15.23	0.33	73.50	0.03	0.37	None	0.53	4.45	4.75	99.19

As stated above the success of the test depends upon the fact that the alkali feldspars upon being heated sufficiently to become a glass do not return readily to their original crystalline state. The fusion takes place at a heat treatment which is too low to permit of any solution of quartz in the feldspar glass, as indicated by Klein.¹

Obviously the distinction between isotropic feldspar glass and crystalline quartz is easily accomplished with the polarizing microscope since with polarized light and crossed nicols the former appears black opaque and the latter shows interference colors.

The test is carried out as follows: The fused product is pulverized and the powder passed through small screens clothed with No. 10 and No. 21 standard silk cloth, the product passing through the No. 10 and retained on No. 21 being tested. The 100- and 200-mesh standard cement screens can be substituted. This operation is done merely to provide a convenient and fairly uniform grain size for examination at a magnification of about 100 diameters.

¹ "Constitution and Microstructure of Porcelain," Bur. of Standards, *Tech. Paper* 80, p. 13.

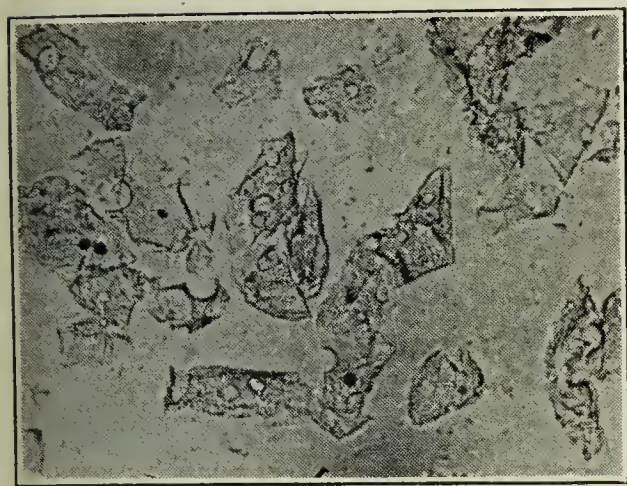


FIG. 1.—Showing grains of quartz-free feldspar, burned at cone 9, taken in ordinary light. Magnification, 100 diam.

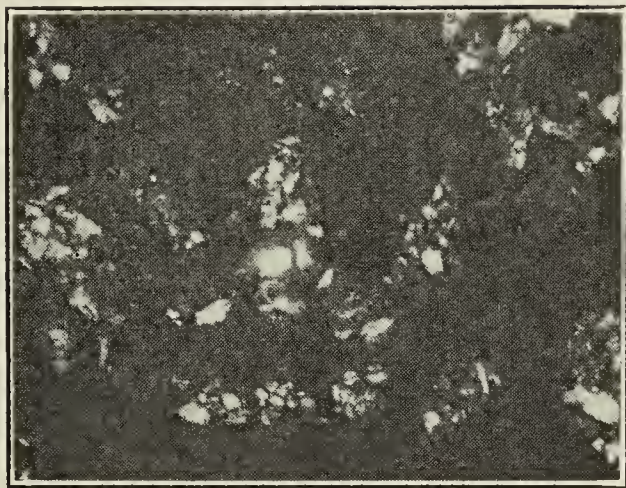


FIG. 2.—Same as Fig. 1, but taken in plane polarized light with crossed nicols. Note the dark feldspar glass and transparent remnants of crystalline feldspar.

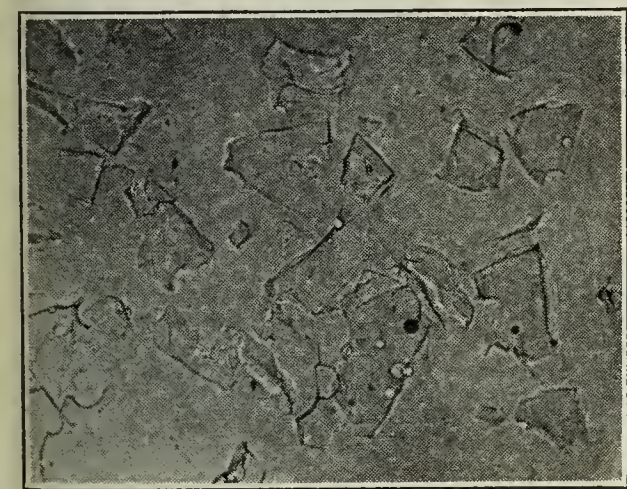


FIG. 3.—Showing grains of quartz-free feldspar, burned at cone 12, taken in ordinary light. Magnification, 100 diam.

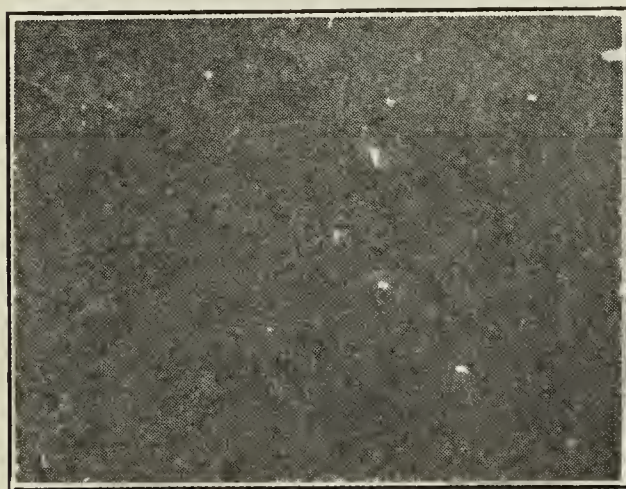


FIG. 4.—Same as Fig. 3, but taken with crossed nicols. The few transparent specks represent a trace of quartz. A comparison with Fig. 2 shows the effect of greater heat in fusing the feldspar.



FIG. 5.—Showing grains of feldspar containing 10% quartz, burned at cone 12, taken in ordinary light. Magnification, 100 diam.

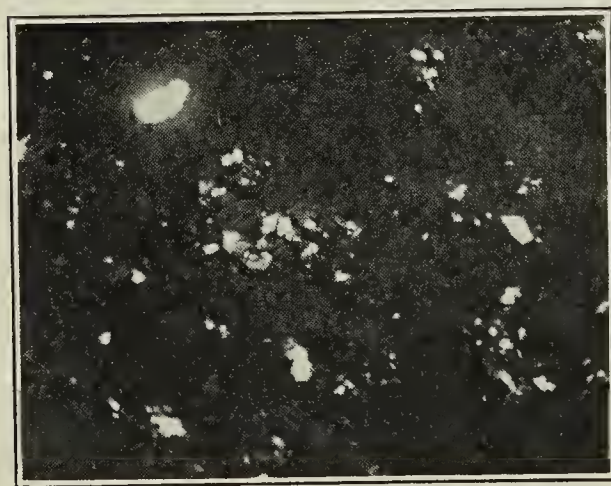


FIG. 6.—Same as Fig. 5, taken with crossed nicols. Note the amount of quartz (transparent grains); their angular outlines indicate that no solution took place.



FIG. 7.—Showing grains of feldspar containing 20% of quartz, burned at cone 12, taken in ordinary light. Magnification, 100 diam.

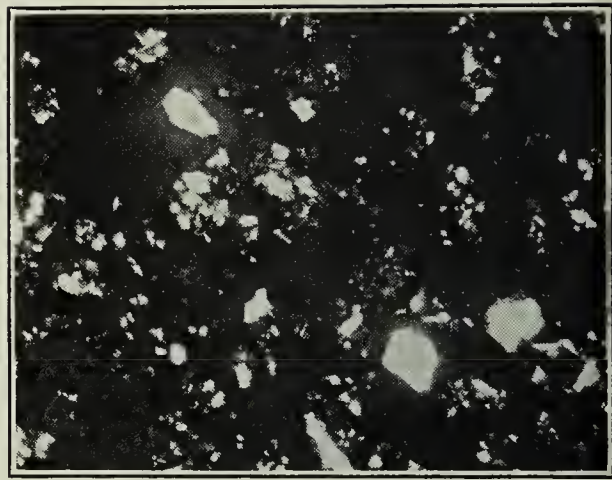


FIG. 8.—Same as Fig. 7 taken with crossed nicols. Note the increased content of quartz over that of Fig. 6.

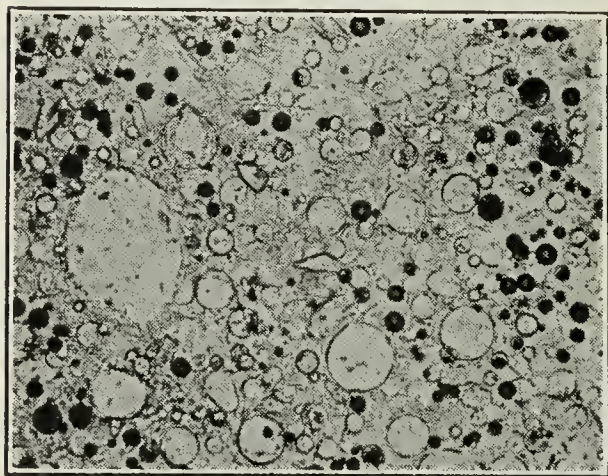


FIG. 9.—Showing thin section of New Hampshire feldspar, burned at specified cone with a 15-minute soak, taken in ordinary light. The circles of various light intensities are blebs. Magnification, 100 diam.



FIG. 10.—Same as Fig. 9, but taken with crossed nicols. Amount of quartz estimated at 10%. Note the lack of evidence of quartz solution.

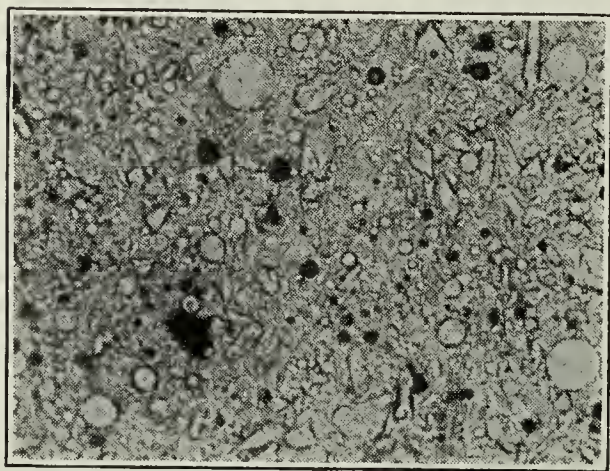


FIG. 11.—Showing thin section of Maine feldspar, burned at specified cone with a 15-minute soak, taken in ordinary light. Magnification, 100 diam.

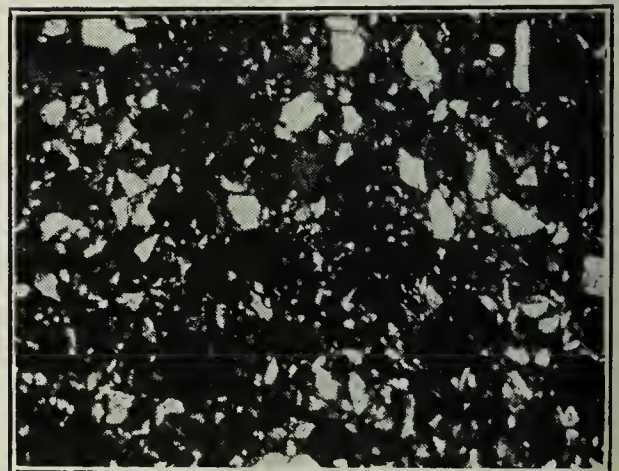


FIG. 12.—Same as Fig. 11 taken with crossed nicols. Quartz content was estimated at 30%. There is no evidence of quartz solution.

A slide is prepared by immersing a small amount of the grain in one of the above mentioned liquids and viewed first in ordinary light by removing the upper nicol prism then in polarized light by inserting it. In ordinary light the total amount of material in the field of vision is seen and in polarized light can be noted the amount of transparent material (quartz). Rotate the stage at least through 45° so that substantially all the quartz grains can be seen in some position or other. If a quartz grain is orientated exactly perpendicular to its "C" crystallographic axis it will remain black on rotation but the very small amount of grains thus orientated has in our experience no effect on the result since any error is well within the accuracy of this method. Quartz grains not so orientated will vary in color from dark gray through white to yellow.

If it is not necessary to determine the amount of quartz but merely to be assured of the uniformity of feldspars it remains only to prepare a permanent slide of a standard sample which shall be compared with subsequent products. Permanent slides are prepared by mounting the grains in a medium which becomes solid on standing, such as Canada balsam.

If it is desirable to know the amount of quartz present a sample of feldspar substantially free from quartz should be procured and to this known amounts of quartz added. Fusions of these mixtures will serve as reference points and permanent slides prepared from them can be compared as indicated with feldspars whose quartz contents are desired.

The ease and rapidity with which these comparisons can be made naturally depend upon the skill and technique acquired by repeated examinations. It is necessary to emphasize, however, that neither knowledge of polarized light nor of petrographic methods is required.

The method requires no elaborate equipment, the most expensive item being the simplest form of a polarizing microscope. Where only an ordinary microscope is available the two nicol prisms can be bought separately and fitted on without much trouble. In addition the following items are necessary: clove oil, Canada balsam, 2 sieves, microscope slides and cover glasses.

Referring to the photographs, Figs. 1, 2, 3, 4, 5, 6, 7, 8 represent the series in which known amounts of quartz were added to a feldspar originally substantially free from quartz. Figs. 9, 10, 11, 12 represent two types of commercial feldspars with differing quartz contents burned at the specified cone but with a difference in time of soak and indicate what variation in heat treatment is possible without producing any discrepancy in the results because of a loss of quartz due to solution in the feldspar glass.

Discussion

A. A. KLEIN:—This method for testing quartz has been used by Norton Company since June, 1922, and has proved very satisfactory. We are blending New Hampshire and Maine feldspar to insure a quartz content of 20%. Weekly samples are taken from the bins and the amount of each feldspar to be used depends upon the results obtained by the application of this method.

J. W. MANOR:—How are the figures arrived at after those slides are examined for percentages of quartz?

A. A. KLEIN:—We take the slides with known quartz content and compare them with the slides of feldspar whose quartz content is desired by the method described. A difference of 5% between them shows up very readily.

H. C. ARNOLD:—Are there any other possible minerals that would occur with feldspar which would not lose their crystalline nature at the point of fusion which he recommends?

A. A. KLEIN:—We have not found any yet. If there were any, they would be present in minor amounts and would not seriously affect the quartz values. Commercial feldspars are composed primarily of minerals of the feldspar group plus quartz and mica. The amounts of other minerals are relatively small.

A. S. WATTS:—Do you think that the artificial mixing of a pure feldspar free from quartz with the silica of commerce would produce a slide which we could use directly comparable to the natural quartz constituent of a pegmatite?

A. A. KLEIN:—Yes.

H. C. ARNOLD:—Do you find in a practical way that the indices of refraction method does not apply satisfactorily to the making of the basis of this investigation?

A. A. KLEIN:—This is not a practical method because most of the feldspars contain plagioclase whose refractive indices may be close to those of quartz itself, and the distinction by this optical constant is, therefore, doubtful. Moreover, even if no plagioclase were present it would be necessary to examine and count a great number of grains to insure reliable results. This would be a tedious task. The distinction between quartz and feldspar of similar indices of refraction by determining the interference is not feasible quantitatively because interference figures of quartz grains orientated parallel or nearly parallel to the "C" crystallographic axis are pseudo-biaxial and therefore not reliable.

H. C. ARNOLD:—I have examined quite a few. We never had such trouble. I wondered how it would be over a long period of time.

A. A. KLEIN:—From our experience the straight petrographic method

is at best a long, tedious one and can be applied with safety only under special conditions.

H. C. ARNOLD:—I am glad that Mr. Klein has presented this paper. I trust that it will be the forerunner of many more of a similar nature. The petrographic microscope is not finding the usage in the ceramic industry that its possibilities warrant. Its position in the study of rocks where the whole classification is based upon microscopic findings shows its possibilities. What can be done with rocks in thin sections can be done with powdered minerals immersed in oil.

I do not understand why Mr. Klein has confined himself to the index of refraction only in distinguishing the various minerals present in a commercial feldspar, nor why he resorts to fusing thereby destroying the very properties of value to him in determining the various ingredients. I would say that he has merely scratched the surface and not shown nearly all the possibilities of the petrographic microscope.

A. A. KLEIN:—The object of the paper was merely the determination of the quartz content of feldspar.

In order to afford a rapid fool-proof method, it was necessary to fuse, since by destroying the very optical properties in the original feldspar the distinction between it and the quartz became so apparent that one little versed in petrography could apply the method.

Our paper simply covered this point and was not a treatise on the general application of the petrographic microscope to ceramic problems. Of these applications we have discussed quite a few in the *Transactions* and the *Journal* and we quite agree that only a beginning has been made.

A STUDY OF THE ORIGIN AND CAUSE OF STONES IN GLASS¹

BY HERBERT INSLEY

ABSTRACT

Stones occurring in glass are caused either by devitrification of the glass, by undissolved batch constituents, or by inclusion in the liquid glass of material from the refractory walls or crown.

Tridymite, cristobalite, wollastonite, diopside, and a new sodium-calcium-silicate are the usual devitrification minerals. In glasses of special composition, such as optical glass, other crystalline compounds are likely to result from devitrification.

Devitrification is the result of inhomogeneity in the melt, wrong batch composition, or exposure of the glass to temperatures favorable to crystallization of some component of the glass.

Incomplete melting is a cause of batch stones. Stones of this type may be due to undissolved sand grains, coloring oxide, or some other constituent. Impurities in the batch often resist solution and remain as stones.

Pot and tank stones are due to inclusions of pieces of the refractory walls in the glass. There are several varieties of such stones. Stones from the white layer on the inside of pots are composed wholly of sillimanite and dissolve with difficulty. Stones derived from tank blocks often contain particles of dehydrated clay matter as well as sillimanite and dissolve more readily than the pure sillimanite stones.

Stones containing corundum (Al_2O_3) are of two types: (1) stones from tank blocks which contained originally nodules of diaspore, bauxite or gibbsite; (2) stones from fire bricks above the glass line in which corundum has formed due to absorption of soda from the furnace atmosphere. The two types may be distinguished by their structure and their associations with other inhomogeneous materials. Determinations of the structure and the optical properties of stones by means of the polarizing microscope often enable one to discover the origin and cause of the stones.

Introduction

"Stones" are segregations of undissolved or crystallized material in glass. They may be introduced into the melt either from the glass and its constituents or from the walls and crown of the tank or pot in which the glass was made. The cause of stones and the means of eliminating them have always been serious problems for the glass manufacturer.

Bowen² has suggested the polarizing microscope as the most useful instrument for determining the composition of stones and has given the optical properties of most of the crystalline materials that are found as stones in optical glass.

The following results of a microscopic examination of a large number of specimens of stones show that there are many different types in the ordinary commercial glasses and that a careful study with the polarizing microscope at the plant will reveal not only their composition and whether

¹ By permission of the Acting Director of the Bureau of Standards of the U. S. Department of Commerce. Presented before the Glass Division, Pittsburgh Meeting, February, 1922.

² N. L. Bowen, "The Identification of Stones in Glass," *Jour. Amer. Ceram. Soc.*, 1, 594-605 (1918).

they came from the glass itself or the refractory walls, but such a study in the case of pot and tank stones will also reveal the approximate position of the blocks that are the source of the stones and will often suggest remedies.

Devitrification Stones

Devitrification stones are caused by the crystallization of some constituent of the glass itself. They often take the form of spherulitic, radiating aggregates of a single crystalline substance.

Since silica is usually the most abundant constituent of a glass, devitri-

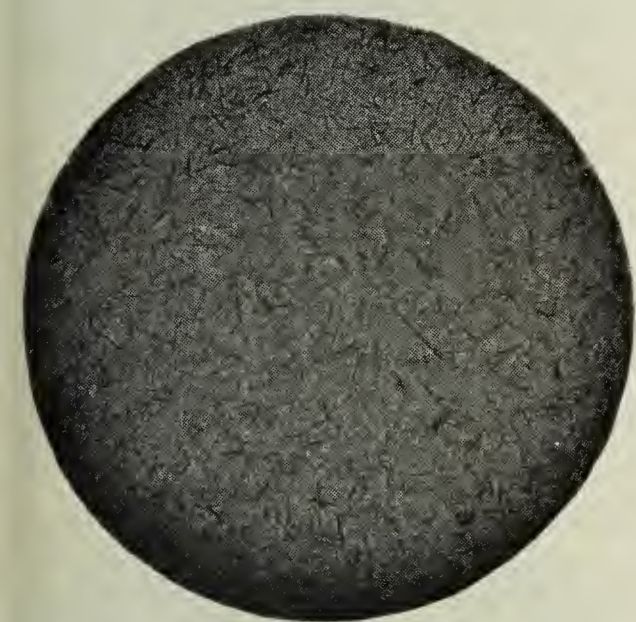


FIG. 1.—Hexagonal plates of tridymite (turned on edge) embedded in glass. Caused by devitrification of bottle glass. Magnification, 50 diam.

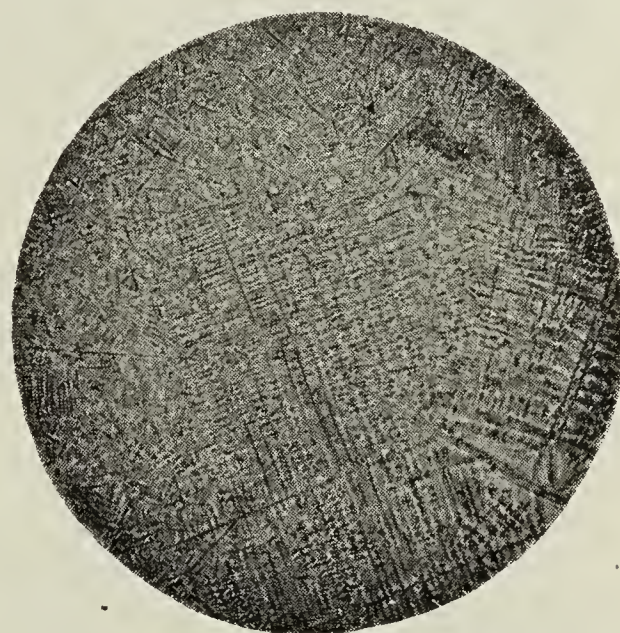


FIG. 2.—Parallel growths of skeleton crystals of cristobalite in devitrified glass from the "dead" regions immediately adjoining the bridge in a tank of bottle glass. Magnification, 50 diam.

fication crystals of the high temperature modifications, tridymite and cristobalite, are not at all unusual. A particularly striking example of this type of devitrification was observed in a piece of bottle glass which had lain in a flow spout between the refining end of the tank and the semi-automatic machine. Flame had been allowed to play on the surface of the glass for several days, the maximum temperature of the surface being from 1100°C to 1200°C . After this heat treatment, the glass contained white, opaque spheres, several of which were 1 inch in diameter. Under the microscope the white spheres were found to be full of what appeared to be crystalline needles embedded in glass. (Fig. 1.) The needles had the negative elongation, low double refraction and low indices of refraction (near 1.47) of hexagonal tridymite plates turned on edge. With a very high power the hexagonal outlines of some of the plates could be seen. The longest dimension of the plates was rarely more than 0.05 mm. and they were less than 0.003 mm. thick.

Devitrification stones which contain cristobalite or mixtures of cristobalite and tridymite have been observed in several instances. A piece of devitrified glass from the "dead" regions immediately adjoining the

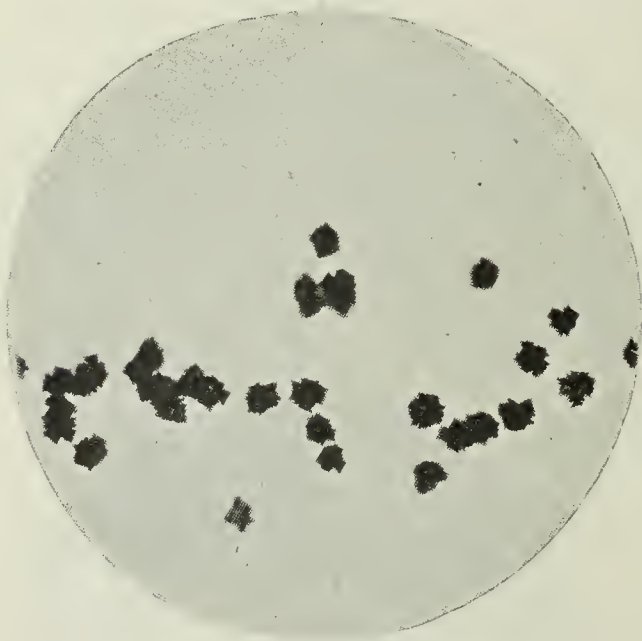


FIG. 3.—Spherulites of cristobalite grouped along striae in lead flint glass. Magnification, 9 diam.

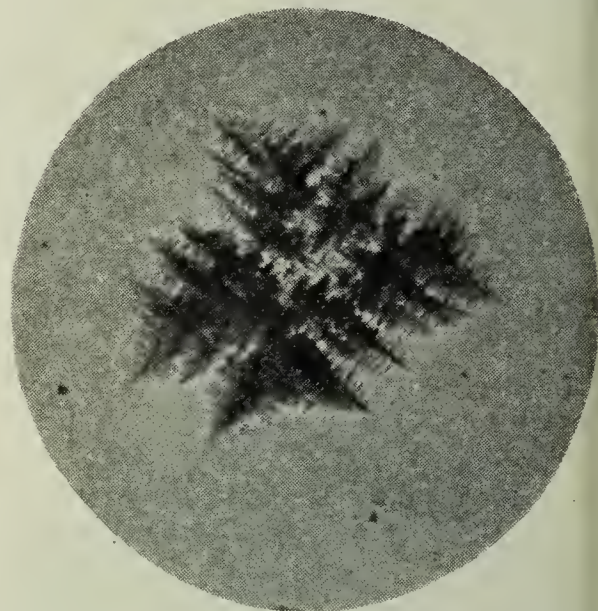


FIG. 4.—One of spherulites in Fig. 3, magnified 47 diameters.

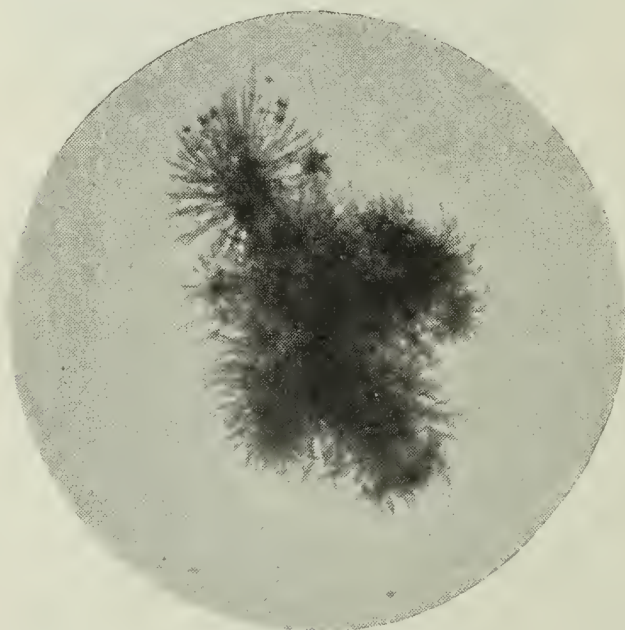


FIG. 5.—Wollastonite spherulite in sheet glass. Magnification, 7 diam.

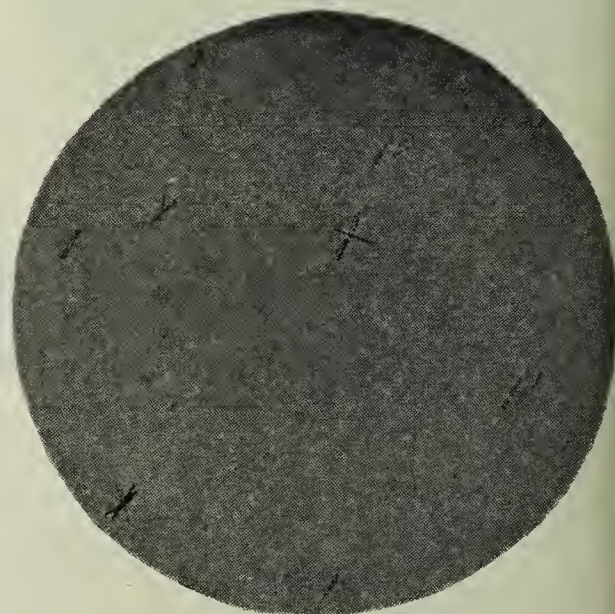


FIG. 6.—Devitrification crystals of a sodium-calcium-silicate in plate glass. Long axes of the crystals are parallel to plane surfaces of the plate glass. Magnification, 8 diam.

bridge in a tank of bottle glass consisted of skeleton crystals of cristobalite which had grown in long parallel arrangements. (Fig. 2.) Individuals had very low double refraction, low indices of refraction (near 1.48) and sometimes showed twinning. The forms mentioned by Fenner¹ were characteristic. The extensive development of the cristobalite and the

¹ C. N. Fenner, "The Stability Relations of the Silica Minerals," *Amer. Jour. Science*, 36 [4], 331-84 (1913).

presence of only a few tridymite crystals would seem to indicate that the temperature was within the range where cristobalite is stable. Apparently devitrification was due to a concentration of silica in that part of the tank.

In a lead flint glass rather high in lead, lines of spherulites of cristobalite followed striae in the glass. (Figs. 3 and 4.) These showed the pine tree forms which are sometimes characteristic of cristobalite spherulites. Devitrification occurred along the striae because they were higher in silica, the crystallizing constituent, than the rest of the glass.

Silicate glasses which are rather high in lime sometimes contain devitrification crystals of wollastonite (CaSiO_3). A particularly large wollastonite spherulite 12 mm. in length was found in a piece of sheet glass. This showed the characteristic radiating plumose structure of wollastonite crystals in glass. (Fig. 5.) One block of window glass containing about 13% lime was full of fine spherulites of wollastonite which were arranged in more or less parallel layers. The layers were somewhat curved and devitrification was apparently due to the fact that these layers contained somewhat more lime than the rest of the glass.

Crystals of a new sodium calcium silicate, the exact composition of which is not known, were first observed in glass by Prof. A. B. Peck. Since that time they have been observed by the writer in at least two specimens of glass. In one they occurred as the crystalline portion of a partly devitrified glass which was taken from the "dead" corner of a glass tank. A piece of plate glass contained the same compound in almost perfect prismatic crystals scattered through the glass and oriented more or less parallel to the plane surfaces of the glass. (Fig. 6.) In arrangement and size these crystals are very similar to wollastonite crystals found by Bowen¹ in a piece of plate glass rather high in lime. The growth of these crystals was ascribed by him to the length of time the glass had been held in the pot immediately before casting. Difference in original composition of the batches probably caused the difference in the kind of crystals formed, but the cause of formation of crystals in both cases was probably the same.

Diopside ($\text{CaMg}(\text{SiO}_3)_2$) sometimes crystallizes as a devitrification product in glass where dolomitic limestone is used in the batch. In one piece of sheet glass examined, long prismatic crystals of diopside grew in a cord in the glass. At the center of the growth the crystals formed a small, radiating tuft. Evidently the cord was somewhat higher in lime and magnesia than the rest of the glass.

Devitrification crystals may be due to several causes, but the manner in which the crystals occur often suggests the true one. Crystals along cords or in layers are probably due in part to inhomogeneity in the melt. Those which occur in large masses or spread evenly through the glass are

¹ N. L. Bowen, "Devitrification of Glass," *Jour. Amer. Ceram. Soc.*, **2**, 271 (1919).

due either to an excess of one constituent in the batch or to the heat treatment during cooling. The crystalline compound formed as the result of devitrification will, of course, depend on the original batch composition and the temperature at which devitrification takes place.¹ There are undoubtedly many other devitrification crystals which have not yet been examined microscopically. Unusual devitrification crystals are likely to occur in glasses of special composition.

Batch Stones

Batch stones are the result of batch constituents or impurities remaining undissolved in the melt. The constituent that is most frequently



FIG. 7.—Batch stone in bottle glass. Partly dissolved quartz grains surrounded by inversion rims of tridymite. Increase of the silica content of the glass in the vicinity of the quartz grains has caused devitrification crystals of tridymite to form. Magnification, 18 diam.



FIG. 8.—Scum from top of melting surface in tank. A mixture of tridymite and cristobalite. Crossed nicols. Magnification, 18 diam.

left undissolved in the melting process is silica. Bowen² has already given the distinguishing characteristics of this type of stone. A typical silica batch stone is shown in Fig. 7. Plates of tridymite (turned on edge in figure) can be seen radiating from centers which are remnants of quartz grains. The quartz centers are surrounded by rims of fine-grained tridymite which show every indication of having gone through an intermediate cristobalite stage.

Salt-cake (sodium sulphate), when it is introduced into the batch in moist lumps, resists decomposition. It then usually rises to the surface as "gall" or scum but sometimes it remains suspended as lumps and white

¹ A more complete discussion of devitrification is given by Bowen in the *Jour. Amer. Ceram. Soc.*, 2, 261-81 (1919).

² N. I. Bowen, "The Identification of Stones in Glass," *loc. cit.*

blotches in the finished glass. These white blotches can be distinguished from devitrification spherulites by the irregular shape of the former. The microscope shows this kind of stone to be made up of agglomerates of very fine particles which are apparently amorphous. Small crystals are sometimes found in them.

Foreign materials in the ingredients are a rather frequent and troublesome source of batch stones. At least two cases were studied where the stones were the result of lumps of clay and soil in the limestone. At times it is difficult to distinguish such stones from clay stones from tank blocks, but generally clay from the limestone does not show such extensive alteration to sillimanite and there are usually characteristics of composition and fineness of grain which are sufficient to distinguish the two types.

When unusual batch ingredients, such as coloring oxides, are used they sometimes contain lumps of impurities which are relatively insoluble in the melt and thus are a source of stones. Difference in grain size and structure and absence of crystalline matter will generally distinguish this kind of stone from stones from other sources. The coloring oxides themselves may be a cause of stones. Davidson¹ has noted that dark spots in chromium green glass are due to undissolved chromium oxide.

Stones caused by particles of "scum" which have become detached from the main mass of the scum and incorporated in the glass can be classed as either batch stones or devitrification stones. Several specimens of the scum which forms on the surface of liquid glass near the melting end of the tank have been examined microscopically and have been found to be composed of a mixture of tridymite, cristobalite and glass. (Fig. 8.) The top of the scum is usually made up of large well-formed hexagonal plates and wedge-shaped twins of tridymite. Near the contact of the scum with the clear glass there is considerable cristobalite mixed in with the tridymite. Thin sections of the scum show circular outlines which are filled with closely packed, wedge-shaped tridymite twins, indicating that a part of the scum was formed from undissolved grains of quartz which floated to the surface of the melt and later inverted to tridymite. A large part of the scum, however, is undoubtedly formed by the devitrification of the highly siliceous liquid at the surface of the melt.

Crown Drops

Since most American furnace crowns are made of silica brick, any liquid that drips from the crown into the glass is likely to be highly siliceous. Crystals of tridymite are often carried with this liquid into the glass. Bowen has described the characteristics of tridymite crystals introduced into the glass with crown drops.

¹ J. H. Davidson in general discussion at meeting of the Society of Glass Technology, reported in *Jour. Soc. Glass Tech.*, 6, 3-17 (1922).

Where fire-clay brick is used in the crown as is sometimes done in England the resulting crown drops will, of course, have an entirely different composition. Such drops will be discussed under tank stones.

Pot or Tank Stones

The most prevalent stones are those produced from the corrosion of pot or tank walls by the molten glass. The appearance of such stones will, of course, depend on the composition of the blocks from which they come, the heat treatment they have undergone, and whether they come from below or above the surface of the glass.

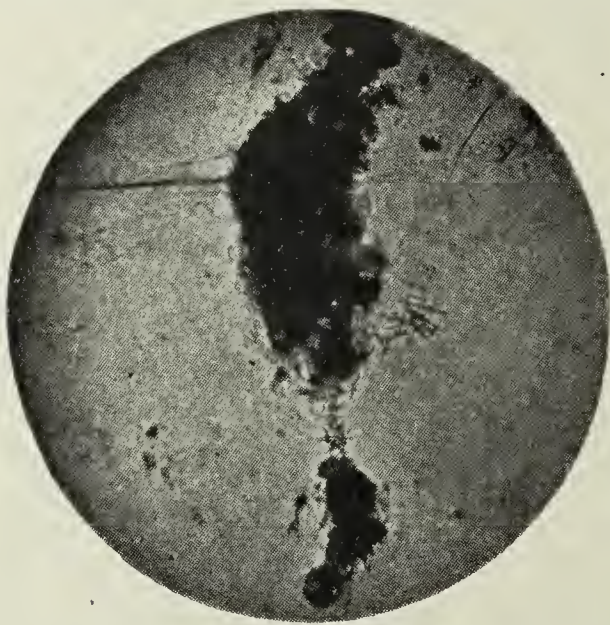


FIG. 9.—Normal clay stone showing mass of fine, amorphous clay particles with partly dissolved quartz grains (at left side of amorphous material) and a few sillimanite crystals (at right side of amorphous material). Magnification, 100 diam.

Stones from below the glass line and from normal fire clays will be first considered. The clay in the inner walls of pots is usually converted to sillimanite and glass, stones from pot walls therefore are composed of this mixture. Stones from tank blocks do not usually show such complete conversion. Corrosion in tank blocks may begin in a crevice or crack into which the glass readily penetrates, finally separating a large piece of clay from the main portion of the tank block. Where such a piece of clay had long exposure to high temperatures but was not in contact with the glass for any length of time before breaking away from the block, large and numerous crystals of sillimanite might form and remain in the glass

after cooling. Microscopic examinations indicate that more often there is not any considerable transformation to sillimanite before the piece of clay is floated away from the tank block. After it is embedded in the glass transformation of clay matter to sillimanite may take place at the periphery. If quartz grains are present, they are gradually dissolved in the glass. The fine, amorphous particles of dehydrated clay matter persist at the center of the piece. (Fig. 9.) A number of specimens of tank stones examined contained such a surprisingly small amount of sillimanite that it seems likely that solution of a portion of the amorphous clay matter in the glass took place before transformation to sillimanite. The relative amount of sillimanite in a tank stone may give some information as to the portion of the tank from which the stone came. Stones which contain large quantities of well-developed sillimanite with little

trace of untransformed amorphous material evidently came from tank blocks which had been exposed to high temperatures for long periods of time.

The discovery of crystals of corundum (Al_2O_3) as stones in glass was surprising and unlooked for as their presence had not heretofore been suspected. Microscopic examination showed that corundum stones were not at all rare and, due to their insolubility in the glass, were probably very persistent.

The position of corundum stones in sheet glass is usually marked by a large lump, the lump being due to the higher viscosity of the glass containing alumina in the immediate vicinity of the corundum crystal.

The presence of corundum in certain tank blocks has been noted by Wilson in a paper¹ which gave the results of a petrographic and chemical analysis of a fire-clay brick which had been in use in the crown of an English tank furnace. The end of the brick which was farthest from the interior of the furnace was apparently unaltered. The zone a little nearer to the interior had a white, vitrified appearance and consisted of minute crystals of sillimanite in a glassy base. The inside end of the brick consisted of a brown glass full of thin, hexagonal plates of corundum. A chemical analysis of the unaltered brick showed about 64% silica, 30% alumina, and about 0.5% alkalis (soda and potash). The fused end of the brick contained about 42% silica, 40% alumina and 10% alkalis. Several analyses of such bricks showed the same remarkable increase in alkalis in the fused ends of the brick as compared to the unaltered ends. The added alkali was undoubtedly largely soda which was absorbed by the brick from the furnace atmosphere. Analyses of the glassy portions of the brick after the content of corundum and sillimanite had been subtracted showed that the molecular ratios of soda to alumina to silica were about 1 to 1 to 5, or, as Wilson supposed, "the composition is made up of about equal proportions of the albite ($\text{Na}_2\text{Al}_2\text{Si}_6\text{O}_{16}$) and the nephelite (or the high-temperature form, carnegite) ($\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$) molecules." At any rate, the increased soda combined with the alumina and silica to form a compound which was liquid at furnace temperatures. If there was excess of both alumina and silica above the ratio necessary for this compound, they united to form sillimanite and if there was still excess alumina after the silica had been satisfied corundum crystallized or if there was still excess silica after the alumina had been satisfied, tridymite or cristobalite crystallized. Thus, depending on the original composition of the brick and the amount of alkalis which had been absorbed from the furnace atmosphere, the fused end of the brick would consist of: (1) silica (tridymite or cristobalite) and liquid, (2) sillimanite, silica and liquid, (3)

¹ G. V. Wilson, "Notes on the Formation of Certain Rock-Forming Minerals in and about Glass Furnaces," *Jour. Soc. Glass Tech.*, 2, 197-213 (1918).

corundum, sillimanite and liquid, or (4), corundum and liquid. Since the alumina in fire bricks is rarely less than the amount required to form the proper proportions with soda and silica for the liquid compound, it is scarcely possible that tridymite or cristobalite will be found in the fused ends of such bricks. As this liquid sodium-aluminum-silicate forms, it will tend to run off the end of the brick and drip down into the glass. Frozen drips of this kind have been collected and analyzed by Wilson.

Wilson does not consider the possibility of corundum being carried into the glass with the drips, but undoubtedly this does happen. The fire brick in the back wall of a pot furnace at the Bureau of Standards used for melting glass were found to be covered with a layer of corundum and glass after the furnace had been in use for some time. Frozen drips depending from the lower edges of some of the bricks consisted of glass and corundum. The percentage of corundum in the drips was not as great as in the end of the brick and probably drips would have ceased to fall after a protecting network of corundum crystals had formed in the end of the brick.

A piece of a clay block from the top of a bridge in a continuous tank where it was exposed to the furnace atmosphere has been examined by the writer. It has many of the characteristics of the brick examined by Wilson. The original clay block from which the specimen came consisted largely of Missouri plastic clay and Missouri or Pennsylvania flint clay. The specimen itself is less than an inch thick. The part which represents the interior of the brick is white and somewhat vitreous and is full of sillimanite needles in a glassy matrix. In portions successively nearer the outside of the brick (the end in the furnace chamber) the sillimanite crystals become larger but less in quantity in relation to the glass until the sillimanite disappears completely and corundum begins to appear. The outer $\frac{3}{8}$ inch is brown and glassy in appearance. The inner part of this brown glass is composed of about 25% corundum and 75% glass. In the extreme outer edge there is slightly more corundum than glass.

The hexagonal plates of corundum in the stones are very similar in appearance to those in the end of the brick just described. (Fig. 10.) In both the crystals are fairly large (0.2–1 mm.) and the crystal faces are sharp and well defined. Inclusions of glass which were originally liquid are characteristic of the corundum crystals in the brick and of those in the stones. These inclusions are arranged approximately parallel to the sides of the hexagonal plates. The evidence as to the source of this kind of stone seems conclusive.

In order to eliminate this type of corundum stone, the possibility of substituting brick containing a very high percentage of alumina and a low percentage of silica should be considered. The amount of sodium aluminum silicate (liquid at furnace temperatures) formed by the absorp-

tion of soda would be so small, that it would not drip off into the glass and would serve merely as a medium in which the corundum could crystallize. The layer of crystalline corundum formed on the surface of the brick should act as a very efficient protective covering for the rest of the brick.

A few samples of stones contained corundum with such different associations and characteristics from those which originated in the brick above the melting surface that a different origin had to be sought for them. In this type the corundum crystals were always small, seldom more than 0.08 mm. in diameter. Generally the crystals had rounded faces, although many showed unmistakable hexagonal outlines. In almost all cases the

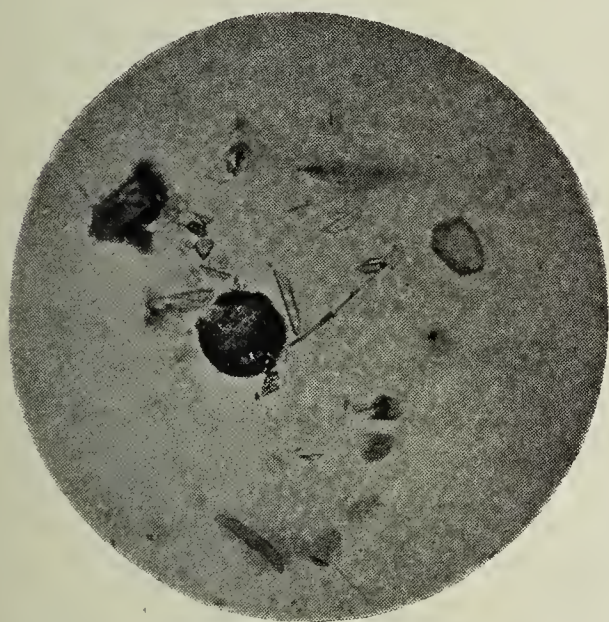


FIG. 10.—Corundum crystals which have dripped off end of fire-clay brick above glass line and fallen into glass. Cloudy areas at upper right and upper left are crystals apparently formed by reaction of the corundum with the glass and are probably sillimanite. The dark circular mass in the center of the photograph is a bubble which has been filled with abrasive material. Magnification, 23 diam.

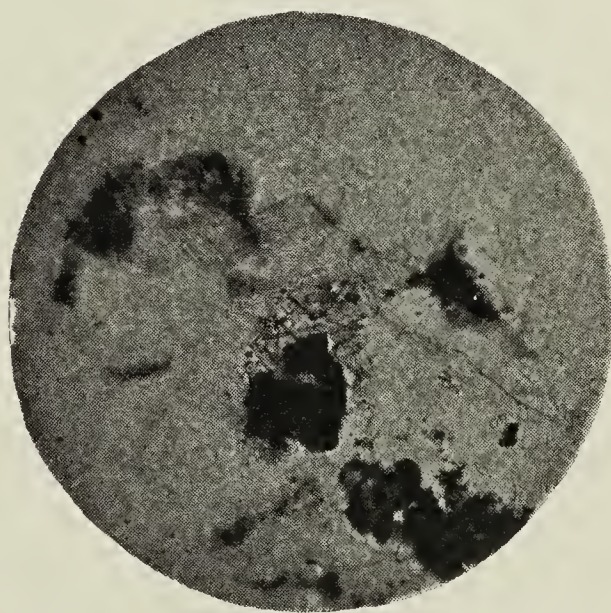


FIG. 11.—Small corundum crystals (in center of figure) in stone in glass, probably caused by conversion of nodules of diasporé to corundum in flint clay. Note amorphous mass just below corundum and crystalline material just above corundum (latter probably formed by reaction between corundum and glass). Magnification, 100 diam.

crystals were found surrounding very fine, apparently amorphous grains with index of refraction as high or almost as high as that of the corundum. (Fig. 11.) In some cases the small corundum crystals and high index amorphous material are associated with normal clay stones with amorphous clay matter in the center and partly dissolved quartz grains and crystals of sillimanite at the periphery.

A microscopic examination of some high alumina refractory blocks which had been used in a Dressler tunnel kiln suggested a possible source for the second type of corundum stone. In these blocks the bond clay

had been transformed to a network of large sillimanite crystals, while the coarser particles contained grains of corundum surrounded by a small amount of sillimanite. The corundum grains, like those noted above, had rounded faces and, in fact, had almost lost all distinguishing crystal form. The original refractory clay had evidently been a so-called "flint" clay which had contained nodules of diaspore ($\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$) or gibbsite ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$). On burning, the bond clay had altered to a mixture of sillimanite needles and siliceous glass and the nodules to corundum. It is well known that certain flint clays, such as those of Missouri, contain nodules of gibbsite or diaspore.

The evidence obtained indicates that the second type of corundum stone originated in pot walls or tank blocks which contained flint clay carrying hydrated aluminum oxide nodules. The high temperatures caused the nodules to change to corundum before the pieces of clay were floated away in the molten glass.

In general there are several characteristics which may serve to differentiate corundum stones originating in tank blocks above the glass line from corundum stones originating in tank blocks below the glass line. In stones originating in blocks above the glass line the crystals are large (0.2 mm.—1 mm.), well formed, hexagonal plates, often containing inclusions of glass. They are never associated with fine particles of amorphous matter or with normal clay stones. When, however, the stones originate in blocks below the glass line, the crystals are small (rarely more than 0.08 mm.), do not often show well-defined faces, and seldom carry inclusions of glass. Often segregations of untransformed particles of amorphous matter remain with the crystals and the crystals are sometimes associated with normal clay stones.

The elimination of corundum stones is very important for corundum stones once formed are relatively insoluble in molten glass of the ordinary soda-lime type.

NOTE: Many of the data given in this paper were obtained on specimens furnished by Mr. D. W. Ross, of the Findlay Clay Pot Co. Thanks are due to him and to Mr. W. F. Brown, chief chemist of the Libbey-Owens Sheet Glass Co., who furnished interesting samples of glass containing stones. The advice of Mr. A. E. Williams, chief of the Glass Section of the Bureau of Standards, has enabled the writer to understand the relations between his laboratory results and commercial melting practice.

CLAY SEWER PIPE MANUFACTURE

II.—The Effect of Variable Alumina, Silica and Iron Oxide in Clays on Some Properties of Salt Glazes¹

By H. G. SCHURECHT²

ABSTRACT

Introduction.—A study was made of the relations between the alumina, silica and iron oxide contents in clays and their ability to take a salt glaze.

Color.—Under the conditions of these tests it was found that low silica clays containing 0 to 1.00% iron oxide and high silica clays containing 0–2.19% iron oxide in terms of calcined weight produced white to tan glazes; low silica clays containing 1.00 to 3.5% and high silica clays containing 2.19 to 3.5% produced light brown glazes; those having 3.5 to 4.75% produced brown glazes; clays containing 4.75 to 8.2% produced mahogany glazes; and those having more than 8.2% possessed dark brown to black glazes.

Brightness.—With clays similar to those tested in this work and which are fired and glazed to the same temperature, the brightness of a salt glaze which will be produced on it, may be predicted by calculating G in the following expression:

$$-1.00x_1 + 0.376x_2 - 2.923x_3 = 100G.$$

x_1 , x_2 and x_3 represent the percentages of alumina, silica and iron oxide in the clay in terms of calcined weight. If G is greater than zero the salt glaze will be bright; when between -0.1337 and 0, it will be semi matt; and when less than -0.1337 it will be matt.

Thickness of Glaze.—The thickness of the salt glaze may be increased 600 per cent by increasing the silica content in a pure clay.

Introduction

Thick smooth glazes on sewer pipe are desirable since they make the pipe more impervious to water and are especially desirable if the body is somewhat porous. The glaze also protects the body of the pipe from the action of chemicals in the sewage as well as the abrasion of sand which is often carried through with the sewage.

The inability of clays to take a salt glaze is largely the cause of unglazed pipe and dull thin glazes. The use of bodies having a composition approaching that best suited for taking a salt glaze would, therefore, result in the production of pipe of better quality, and reduce losses in their manufacture.

That some clays take a salt glaze better than others is known, but what the composition of a clay should be to take a salt glaze is not known. Langenbeck³ suggested that a clay must have 8 molecules of silica to one

¹ Published through the courtesy of The Eastern Clay Products Association and The Clay Products Association under whose auspices this work has been conducted as a part of their research program on the manufacture of clay sewer pipe. A third paper on this subject will appear in the *July Journal*.

² Industrial Fellow, The Mellon Institute of Industrial Research, University of Pittsburgh, Pa.

³ Karl Langenbeck, "Chemistry of Pottery," 90.

of alumina before it will take a good salt glaze; Barringer¹ reported that 4.6 molecules of silica is the lower limit; while Mackler² stated that clays having 3.3 molecules of silica to one of alumina will take a salt glaze.

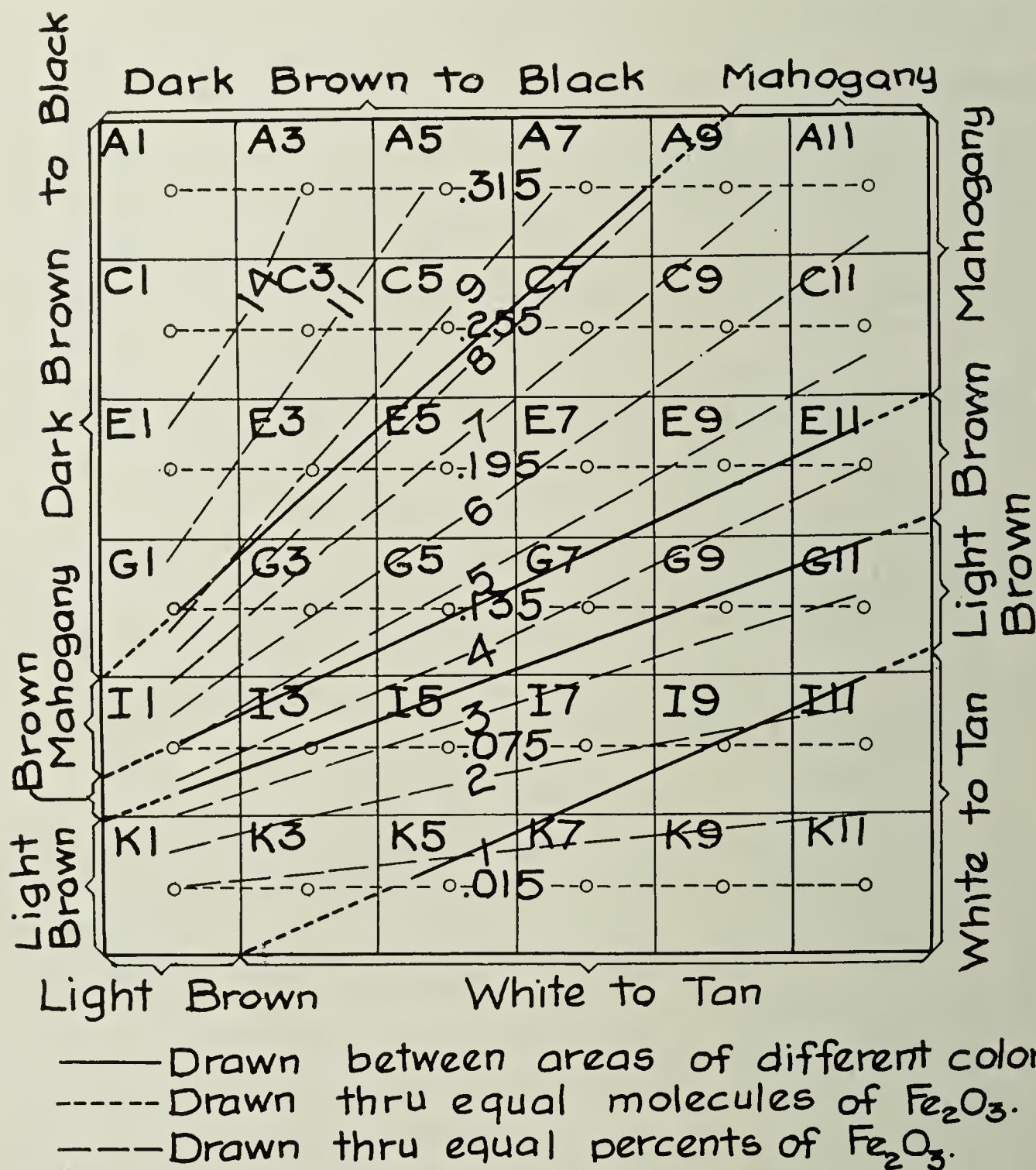


FIG. 1.—The influence of iron oxide on the color of salt glazes.

Experimental Methods of Present Study

Thirty-six synthetic clays with varying chemical compositions were prepared. The silica, alumina and iron oxide contents were varied between the following limits:

Alumina (Al_2O_3) = 12.30–37.18%.

Silica (SiO_2) = 38.40–80.95%.

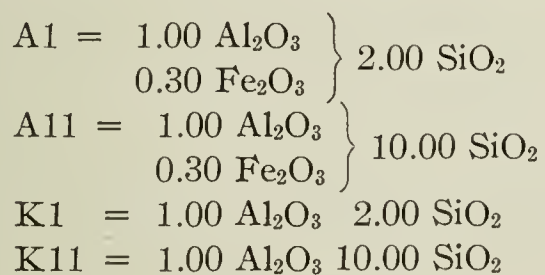
Iron oxide (Fe_2O_3) = 0.33–16.40%.

¹ L. E. Barringer, *Trans. Amer. Ceram. Soc.*, **4**, 222 (1902).

² Mackler, *Tonind. Ztg.*, **251**, 440 (1905).

The mixtures were prepared by adding varying amounts of potter's flint and iron oxide to a 1:1 Florida kaolin-Tennessee ball clay mixture. The clays had a composition corresponding closely to that of a pure clay and at the same time were fine grained having a structure very similar to the secondary clays used for sewer pipe manufacture. Since impure clays are usually mixtures of a pure clay and minerals, the addition of flint and iron oxide to these produces a mixture which has a mineralogical composition similar to the impure clays used for the manufacture of sewer pipe.

The mixtures were prepared according to the diagram shown in Fig. 1. The four corners correspond to the following compositions:



The raw mixtures were molded into $1\frac{1}{2}'' \times 1\frac{1}{2}'' \times 1\frac{3}{4}''$ briquettes which were scored on two sides to facilitate in breaking them for a microscopic examination of the different glazes produced on them. These trial pieces were set in clay pats together with standard cones and were fired and salt glazed in a commercial sewer pipe kiln at cones 2-3. To check the deformation cone on the test pat, which was exposed to salt fumes during the glazing, similar cones were also placed in small saggers near the test pat. Thus the deformation cone in the absence of salt fumes was obtained as well as that softening in the presence of salt fumes. In this test cone 3 deformed outside of the sagger and cone 2 inside.

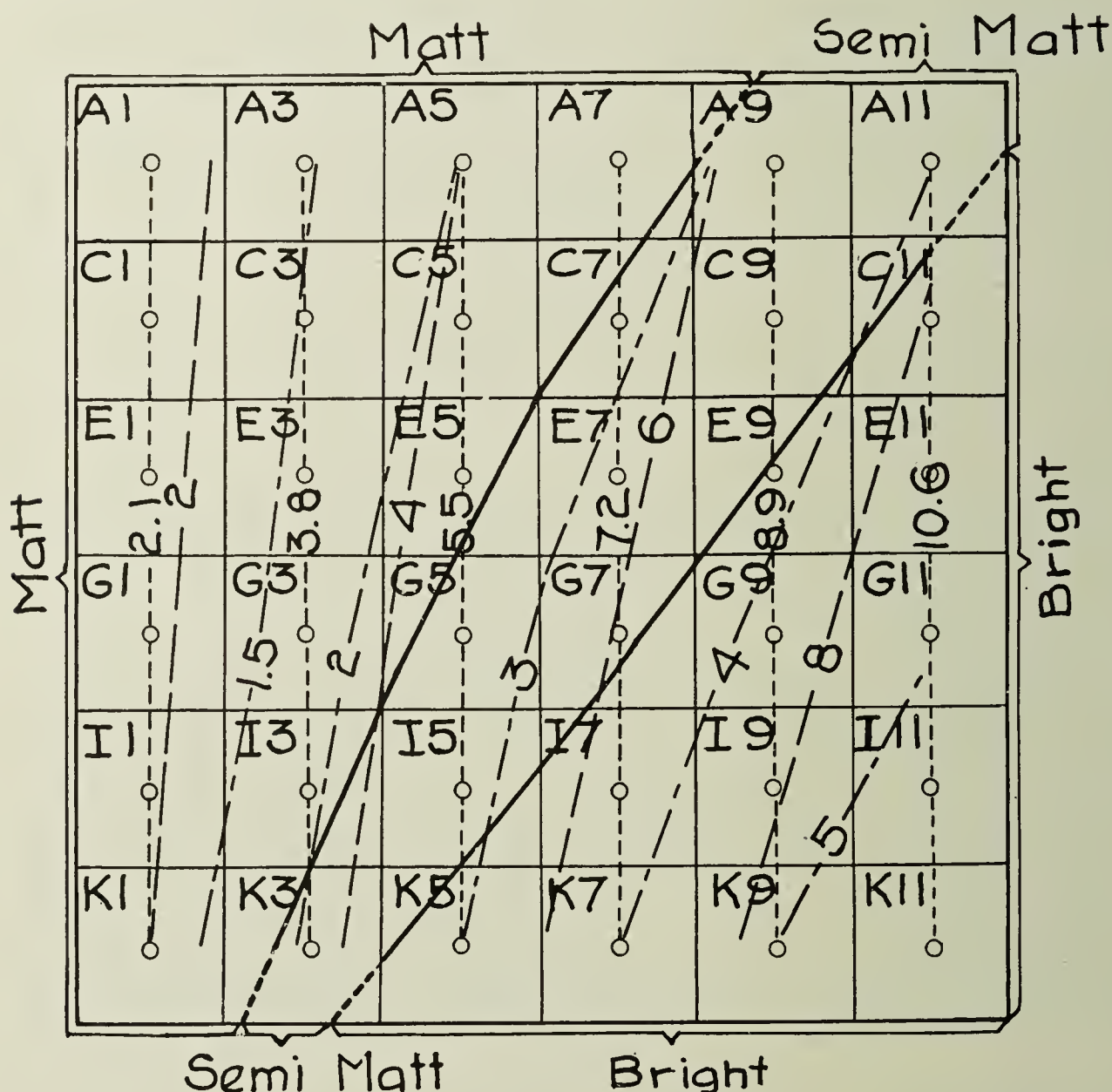
After the specimens had been fired and glazed, they were broken and the thicknesses of the different glazes were measured under a microscope.

Experimental Results

The Effect of Variable Silica, Alumina and Iron Oxide in Clays on the Color of Salt Glazes.—The effects of different ingredients in clay upon the color of salt glazes are shown in Fig. 1. The squares lettered A-1.....K-11 represent the different mixtures. The dotted lines are drawn through the points which represent mixtures having the same molecular quantities of iron oxide while the dash lines pass through points which have the same percentage iron oxide in terms of the calcined weight of the mixture. The areas having different colors are separated by heavy solid lines and the colors of these are indicated on the margins.

The lines separating the different areas coincide fairly closely with those representing equal *percentages* of iron oxide. For example those clays which have more than 8.2% iron oxide produce a dark brown to a black glaze; those containing between 4.75 and 8.2% iron oxide take mahogany

glazes; and those having between 3.5 and 4.75% produce brown glazes. The dividing line between light brown and white to tan glazes does not coincide with the line representing equal percentages iron oxide but varies from 1.00 to 2.19% iron oxide for clays containing 54.90 to 83.75% silica respectively.



- Drawn between areas of different glossiness.
- Drawn thru equal ratios of mols. $\text{SiO}_2 \div \text{Al}_2\text{O}_3$.
- Drawn thru equal ratios of mols. $\text{SiO}_2 \div (\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)$.
- Drawn thru equal ratios of $\% \text{SiO}_2 \div \% (\text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3)$.

FIG. 2.—The influence of the chemical composition of clays on the glossiness of salt glazes.

The dotted lines drawn through squares, representing clays having equal *molecular proportions* of iron oxide (unlike the case of equal percentages) in no cases coincide with the lines dividing the areas of different color but instead cross these showing that there is no close relation between the molecular quantities of iron oxide and the color of the glaze.

The Effect of Variable Silica, Alumina and Iron Oxide in Clays on the Brightness of Salt Glazes.—The relation between the variable silica, alumina and iron oxide contents in clays on the brightness of salt glazes is shown in Fig. 2. The dotted lines are drawn through points representing clays having equal ratios of molecules of silica to molecules of alumina. The dash lines pass through points having equal ratios of molecules of silica to molecules of alumina plus iron oxide and the dot and dash lines are drawn through points having equal ratios of per cent silica to per cent alumina plus iron oxide.

The heavy solid lines are drawn between areas having different degrees of brightness and these areas are designated in the margins as bright, semi matt and matt glazes. By matt glazes are meant dull rough glazes having the appearance of vitrified clay without a glaze. Bright glazes are those which have a bright and glossy appearance similar to glass. By semi matt glazes are meant those which are too dull to be classed as bright but still are not as dull as the true matt glazes. Those semi matt glazes lying near the bright glaze area have only a thin matt skin on the surface of the glaze which can only be seen by looking at the glaze at an angle, while the semi matt glazes near the matt glaze area have a thick matt skin.

By examining the diagram it is seen that neither the dotted, dash or dot and dash lines coincide with the lines separating the gloss, semi matt and matt areas, showing that there is no close relation between the glossiness of salt glazes and ratios of molecules of silica to molecules of alumina, molecules of silica to molecules of alumina plus iron oxide or percentage silica to percentage of alumina plus iron oxide.

With clays containing no iron oxide, the division between semi matt and bright glazes falls upon a clay having a ratio of percentage silica to percentage alumina of 2.66 while with those containing 6% iron oxide, the division falls on a clay whose ratio of percentage silica to percentage alumina plus iron oxide is 4.28. It is evident that the iron oxide under the conditions of this experiment has a greater tendency to produce matt glazes than alumina. In order to show this difference mathematically the writer determined gloss values for the three oxides in the following formula which may be used within the limits of composition of this experiment to predict what type of glaze a similar clay will take from the chemical analysis.

$$x_1g_1 + x_2g_2 + x_3g_3 = 100G \quad (1)$$

x_1 , x_2 and x_3 represent, respectively, the percentages of alumina, silica and iron oxide in clays in terms of calcined weight; g_1 , g_2 and g_3 represent the gloss values which were found to be —1.00, 0.376 and —2.923 for alumina, silica and iron oxide, respectively, and G represents the gloss factor of the glaze produced with this clay which increases in proportion

to the brightness of the glaze produced. Thus by substituting the percentages of the oxides in terms of calcined weight of clay in the above equation and multiplying each by their respective gloss values, a value G , may be calculated. When G is greater than 0 the clay will produce a bright glaze provided it is fired under conditions similar to those under which the test pieces were fired. When G is between -0.1337 and 0 the glazes will be semi matt and when below -0.1337 they will be matt.

The above gloss values were determined from this first experiment only. The values for silica and alumina will probably be about the same for all conditions but that for iron oxide will vary for different kiln atmospheres. Under reducing conditions it will be -2.923 . Just how much it will be changed will be determined in subsequent work and after having been estimated it will enable the burner to predict how much the glaze will be changed by varying the kiln atmosphere from oxidizing to reducing in firing.

Mathematical Derivations.—The percentages of silica and alumina in a clay having a ratio of percentage silica to percentage alumina of 2.28 are 72.70 and 27.30, respectively. This composition represents, therefore, the division between bright and semi matt glazes in the iron-free mixture.

Giving to g_1 the value -1.00 and to G the value 0, we obtain a value for g_2 by means of equation 1 as follows:—

$$27.30 (-1.00) + 72.70g_2 + 0g_3 = (100) (0)$$

$$g_2 = \frac{27.30}{72.70} = 0.376$$

The ratio of percentage silica to percentage alumina plus iron oxide in clays having a composition falling upon the dividing line between bright and semi matt glazes is 4.28 for clays containing 6 per cent iron oxide. The percentages alumina and silica for such a clay may be calculated as follows:

$$x_1 + x_2 + 6 = 100$$

$$\frac{x_2}{x_1 + 6} = 4.24$$

$$\therefore x_1 = 12.91 \text{ and } x_2 = 81.09.$$

Substituting these values in equation 1 with G equal to 0 we can calculate a value for g_3 as follows:

$$(12.91) (-1.00) + (81.09) (0.376) + 6(g_3) = (100) (0)$$

$$g_3 = -2.923.$$

Substituting these gloss values for alumina, silica and iron oxide, the ratios, (R_1), of per cent silica to per cent alumina plus iron oxide were determined for different values of x_3 as follows:—

$$\begin{aligned}\text{For } x_3 = 1 \quad & x_1(-1.00) + x_2(0.376) + 1(-2.923) = 0 \\ & -99 + x_2(0.376) - 2.934 = 0 \\ & x_2 = 74 \\ & R_1 = 2.84\end{aligned}$$

$$\text{For } x_3 = 2, R_1 = 3.08.$$

$$\text{For } x_3 = 6, R_1 = 4.28.$$

In this manner it was found that

$$R_1 = f(x_3) = (0.162 + 0.01x_3^{1.328})x_3 + 2.66 \quad (2)$$

When a line is drawn through points (Fig. 2) having values of R_1 equal to the above expression it was found to divide the bright glazes from the semi matt glazes as accurately as it is possible to detect by a visual examination, and therefore, for practical purposes may be used to represent the ratios of per cent silica to per cent alumina plus iron oxide dividing the bright and semi matt glazes.

We find by examining the iron free clays that the division point between matt and semi matt glazes is represented by the mixture in which the ratio of per cent silica to per cent alumina plus iron oxide is 1.70. Using the same gloss values as were determined above for the oxides in this clay, we obtain -0.1337 as the gloss factor G , which divides the matt from semi matt salt glazes produced on the iron-free mixtures. This value for G was calculated as follows:

$$\begin{aligned}(37.02)(-1.00) + (62.98)(0.376) + 0(-2.923) &= 100G. \\ G &= -0.1337.\end{aligned}$$

The ratios, (R_2), of per cent silica to per cent alumina plus iron oxide for clays containing 6% iron oxide and having a gloss factor, G , of -13.37 , was found to be 2.51 as follows:

$$\begin{aligned}x_1(-1.00) + x_2(0.376) + 6(-2.923) &= (100)(-0.1337) \\ -94 + 1.376 x_2 - 17.538 &= 13.37. \\ x_2 &= 71.30 \\ R_2 &= 2.51\end{aligned}$$

$$R_2 = f(x_3) = (0.105 + 0.001x_3^{1.898})x_3 + 1.70 \quad (3)$$

Equation 3 was obtained in a manner similar to that used in obtaining Equation 2. The values for R_2 when plotted on the gloss diagram (Fig. 2) were found to divide the semi matt and matt area as accurately as was possible by a visual examination of the glaze.

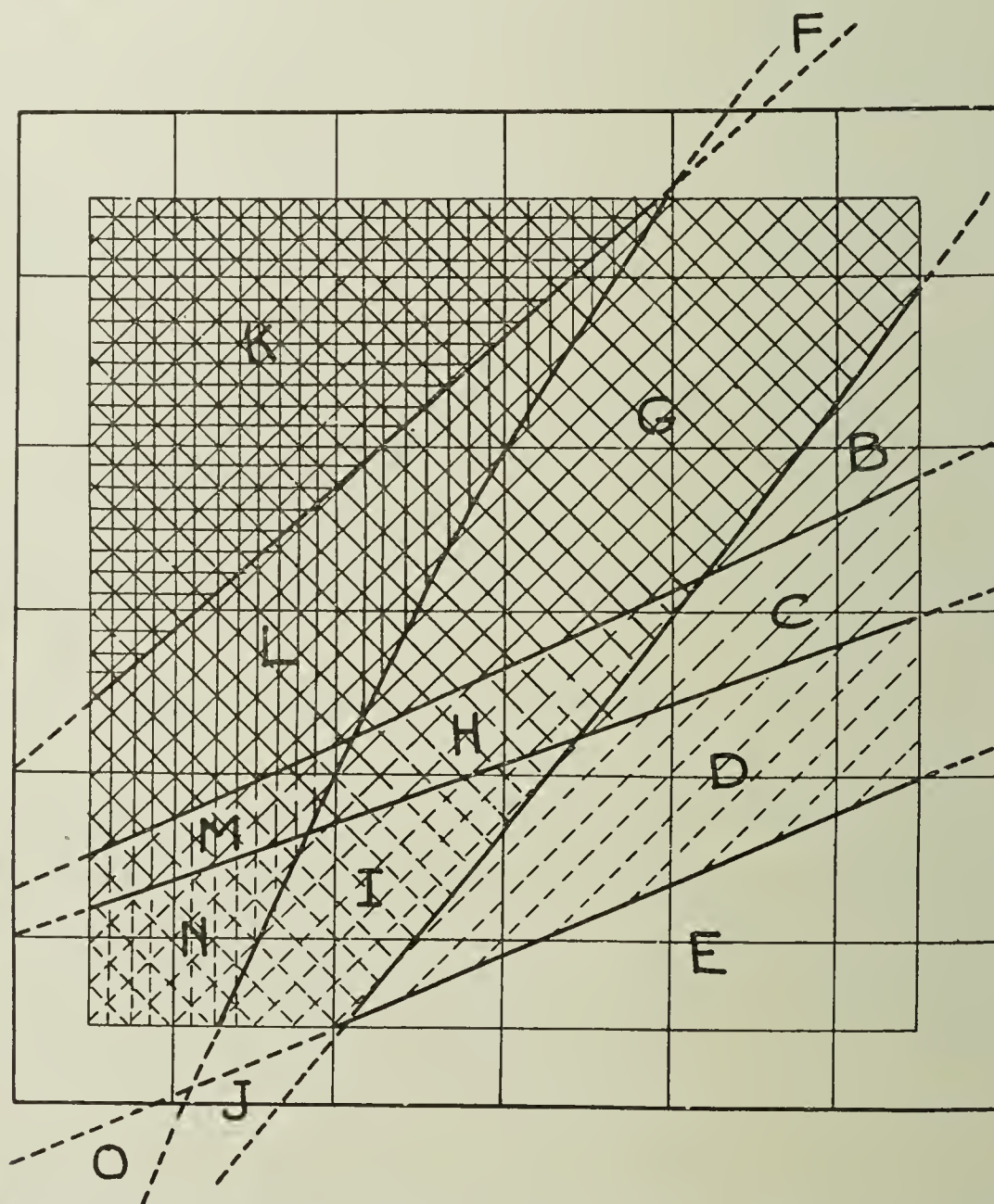
According to Sortwell¹ porcelain glazes having the best gloss have their molecular quantities of alumina equal to 0.3 plus $1/12$ silica. This value for some iron-free salt glazes which are similar to porcelain glazes in composition would correspond to a glaze having a ratio of per cent silica to per cent alumina of 5.30. The gloss value G for such glazes would be $+0.1576$

¹ H. H. Sortwell, "High Fire Porcelain Glazes," *Jour. Amer. Ceram. Soc.*, **4**, 729 (1921).

and the values for the ratios (R_3) per cent silica to per cent alumina plus iron oxide for clays having this gloss factor would approximately be as follows

$$R_3 = (0.48 + 0.01x_3^{2.386})x_3 + 5.30 \quad (4)$$

The writer has not yet covered the high iron oxide clays having the value for G experimentally but it is probable that the glazes of higher gloss would be produced on clays having values for R_3 represented approximately by equation 4.



B—Mahogany Bright. I—Light Brown Semi Matt.
 C—Brown Bright. J—White to Tan Semi Matt.
 D—Light Brown Bright. K—Dark Brown to
 E—White to Tan Bright. Black Matt.
 F—Dark Brown to L—Mahogany Matt.
 Black Semi Matt. M—Brown Matt.
 G—Mahogany Semi Matt. N—Light Brown Matt.
 H—Brown Semi Matt. O—White to Tan Matt.

FIG. 3.—The influence of variable silica, alumina and iron oxide in clays on the color and gloss of salt glazes.

In reviewing the literature¹ on the crazing of glazes it was found that for porcelain glazes this occurs when the gloss factor lies above 0.16–0.20. The values for G were calculated from the ratio of per cent silica to per cent alumina in the glazes similar to salt glazes in composition.

Since clays having this gloss value are very rare and usually have a lower ratio it is obvious that the danger of crazing due to too much silica in the sewer pipe clays is very slight and that silica can be added to the majority of clays without danger of causing crazing of the glazes.

In the place of equations 2, 3 and 4 the following equations 5, 6 and 7 may be used, which although not as accurate as the first equations are much simpler and within the limits covered in this investigation are sufficiently close for practical purposes:

$$R_1 = (0.162 + 0.018x_3)x_3 + 2.66 \quad (5)$$

$$R_2 = (0.105 + 0.005x_3)x_3 + 1.70 \quad (6)$$

$$R_3 = (0.48 + 0.12x_3)x_3 + 5.30 \quad (7)$$

The limits of the ratios of per cent silica to per cent alumina plus iron oxide between matt, semi matt and bright glazes are given by the following expressions for glazes of varying silica, alumina and iron oxide contents.

Glossiness of the salt glaze	Ratios of per cent silica to per cent alumina plus iron oxide
Matt	<1.20 to $(0.105 + 0.005x_3)x_3 + 1.70$
Semi Matt	$(0.105 + 0.005x_3)x_3 + 1.70$ to $(0.162 + 0.018x_3)x_3 + 2.66$
Bright	$(0.162 + 0.018x_3)x_3 + 2.66$ to $>(0.48 + 0.12x_3)x_3 + 5.30$

The glazes were divided into 15 groups according to their color and brightness (Fig. 3). The limits in composition of these are given in Table I.

The Effect of Variable Silica, Alumina and Iron Oxide in Clays on the Thickness of Glaze and

Vitrified Surface Produced by

Salt Glazing.—The 36 glazed trial pieces were split in two and the thicknesses of the glazes measured under a microscope.

When thus examined the series which contained practically no iron oxide showed a sharp division line between the glassy glaze and the crystalline

body, making it easy to measure the thickness of the glaze. The results of the measurements of the thicknesses of glazes in this series are shown in Fig. 4. It is obvious that raising the silica content in clays increases the thickness of the resultant salt glaze to a marked extent. This thickness

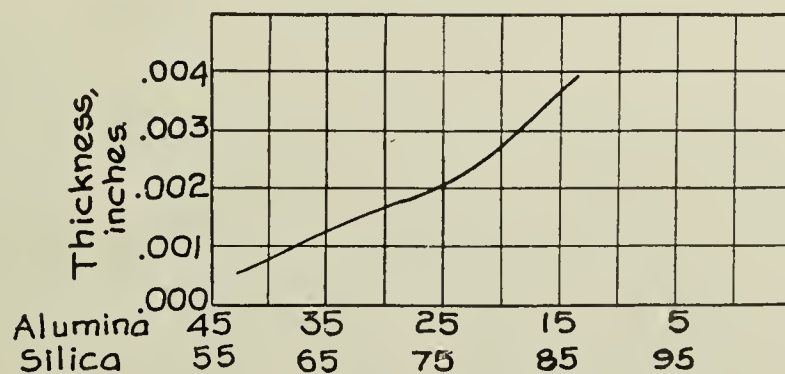


FIG. 4.—The effect of variable silica and alumina in clays on the thickness of glaze produced at cone 3, 1190°C, 2174°F.

¹ R. T. Stull, "Influence of Variable Silica and Alumina on Porcelain Glazes," *Trans. Amer. Ceram. Soc.*, 14, 62 (1912); H. H. Sortwell, *loc. cit.*

TABLE I
LIMITS IN COMPOSITION OF CLAYS WHICH WILL PRODUCE DIFFERENT SALT GLAZES

Description	Limits of iron oxide (Fe ₂ O ₃), per cent	Ratio of per cent silica to per cent alumina plus iron oxide in clay		Gloss factor
A. Dark brown to black bright glazes.....	8.2 to > 12.33	(.162 + 0.018x ₃)x ₃ + 2.66 to > (0.48 + .12x ₃)x ₃ + 5.30	0 to > 0.1576	
B. Mahogany bright glazes.....	4.75 to 8.20	(.162 + 0.018x ₃)x ₃ + 2.66 to > (0.48 + .12x ₃)x ₃ + 5.30	0 to > 0.1576	
C. Brown bright glazes.....	3.50 to 4.75	(.162 + 0.018x ₃)x ₃ + 2.66 to > (0.48 + .12x ₃)x ₃ + 5.30	0 to > 0.1576	
D. Light brown bright glazes.....	1.00-2.19 to 3.50	(.162 + 0.018x ₃)x ₃ + 2.66 to > (0.48 + .12x ₃)x ₃ + 5.30	0 to > 0.1576	
E. White to tan bright glazes.....	0 to 1.00-2.19	(.162 + 0.018x ₃)x ₃ + 2.66 to > (0.48 + .12x ₃)x ₃ + 5.30	0 to > 0.1576	
F. Dark brown to black semi matt glazes.....	8.2 to > 12.33	(.105 + 0.005x ₃)x ₃ + 1.70 to (.162 + 0.018x ₃)x ₃ + 2.66	— .1337 to 0	
G. Mahogany semi matt glazes...	4.75 to 8.20	(.105 + 0.005x ₃)x ₃ + 1.70 to (.162 + 0.018x ₃)x ₃ + 2.66	— .1337 to 0	
H. Brown semi matt glazes.....	3.50 to 4.75	(.105 + 0.005x ₃)x ₃ + 1.70 to (.162 + 0.018x ₃)x ₃ + 2.66	— .1337 to 0	
I. Light brown semi matt glazes..	1.00-2.19 to 3.50	(.105 + 0.005x ₃)x ₃ + 1.70 to (.162 + 0.018x ₃)x ₃ + 2.66	— .1337 to 0	
J. White to tan semi matt glazes..	0 to 1.00-2.19	(.105 + 0.005x ₃)x ₃ + 1.70 to (.162 + 0.018x ₃)x ₃ + 2.66	— .1337 to 0	
K. Dark brown to black matt glazes.....	8.2 to > 12.33	< 0.98 to (.105 + .005x ₃)x ₃ + 1.70	< — .24 to — .1337	
L. Mahogany matt glazes.....	4.75 to 8.20	< 0.98 to (.105 + .005x ₃)x ₃ + 1.70	< — .24 to — .1337	
M. Brown matt glazes.....	3.50 to 4.75	< 0.98 to (.105 + .005x ₃)x ₃ + 1.70	< — .24 to — .1337	
N. Light brown matt glazes.....	1.00-2.19 to 3.50	< 0.98 to (.105 + .005x ₃)x ₃ + 1.70	< — .24 to — .1337	
O. White to tan matt glazes.	0 to 1.00-2.19	< 0.98 to (.105 + .005x ₃)x ₃ + 1.70	< — .24 to — .1337	

was increased about 600% by raising the silica content from 54 to 85.33%.

In examining the trial pieces containing considerable iron oxide it was observed that there was a black vitrified area underneath the glazes. The thickness of this black portion increased with the iron oxide content. It was difficult to distinguish between the glass and this black vitreous area which encased the entire test piece and therefore the total thickness of vitrified casing plus salt glaze produced was measured and the results are shown in Fig. 5.

Since the thickness of the vitreous casing underneath the salt glaze becomes greater with an increase in iron oxide we find that glazes in area K, (Fig. 3) have the largest values for the sum of vitrified casing plus glaze. Since the color of this vitreous casing is black it probably exerts an important influence on the color of the more or less transparent glazes.

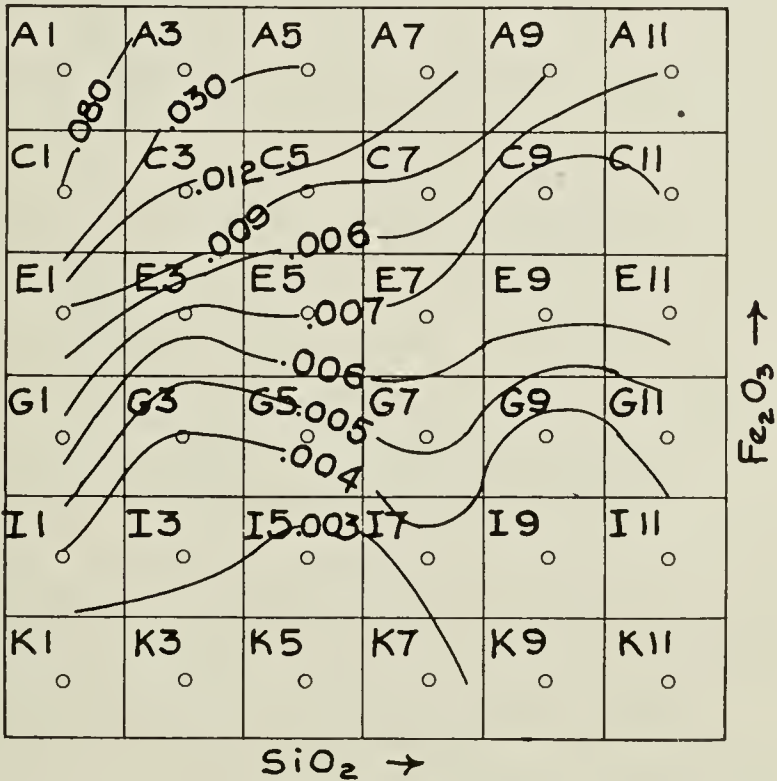


FIG. 5.—The effect of variable chemical composition of clays on the thickness of the vitrified surface and glaze produced by salt glazing.

The Relation between Geological Ages of Clays and the Type of Salt Glaze Produced

In Table II is shown the relation between the geological age and the type of salt glaze predicted for some clays. The letters A to O represent the different areas (Fig. 3) in which the glazes produced by these clays lie. These results show that there is no definite relation between the geological age and the type of glaze obtained since clays in the same geological age may vary from those highly desirable for sewer pipe glazes to others unsuitable for the production of salt glazes. (Table II.)

TABLE II

Geological Age	Bright					Semi matt					Matt				
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Lower Carboniferous					2						3	2			1
Coal Measures		2	2	2	3		3	1	3	4	5	2	1	2	1
Residual					1	1			1	1	1			1	2
Pleistocene							3					2			
Lower Kittanning										1					1

Summary and Conclusions

The effects of variable silica, alumina and iron oxide on the ability of different clays to take a salt glaze were studied. The salt glazing was performed at cone 2, 1170°C, 2138°F, in a commercial sewer pipe kiln under normal conditions. The limits given below would vary considerably if salting was done under strongly reducing conditions and at a different temperature than that given above.

Although the results apply in general to most clays, strictly speaking they only hold true with clays in which the chief constituents are alumina, silica and iron oxide, with the other impurities totaling less than 1.4 per cent and where all minerals are finer than 100-mesh size.

1. There is a closer relation between color of salt glazes and the per cent iron oxide in clays than between the color and the molecules of iron oxide as used in ceramic formulas for glazes.

2. Black to dark brown glazes are obtained when the clays contain more than 8.2% iron oxide in terms of calcined weight.

3. Mahogany glazes are produced when the clays contain 4.75–8.2% iron oxide in terms of the calcined weight of clay.

4. Brown glazes are obtained when the clays contain 3.5–4.75% iron oxide in terms of calcined weight of clay.

5. Light brown glazes are produced when the clay contains 1.00–2.19 to 3.5% of iron oxide in terms of calcined weight of clay.

6. White to tan glazes are obtained when the clay contains 0 to 1.00–2.19% iron oxide in terms of the calcined weight of clay.

7. The glazes were divided into three groups and are designated as bright, semi matt and matt glazes. The ratios of per cent silica to per cent alumina plus iron oxide bear the closest relation to these areas which fall between the following limits of these ratios:

Matt glazes $\cong < 1.20$ to $(0.105 + 0.005x_3)x_3 + 1.70$

Semi matt glazes = $(0.105 + 0.005x_3)x_3 + 1.70$ to $(0.162 + 0.018x_3)x_3 + 2.66$.

Bright glazes = $(0.162 + 0.018x_3)x_3 + 2.66$ to 5.30

8. Gloss values were determined for alumina, silica and iron oxide from which a gloss factor of the glaze produced by a similar clay may be calculated by means of a formula from its chemical analyses as follows:

$$x_1g_1 + x_2g_2 + x_3g_3 = 100G.$$

In this equation x_1 , x_2 and x_3 are the percentages alumina, silica and iron oxide, respectively, in the clay in terms of calcined weight and g_1 , g_2 and g_3 are gloss factors for alumina, silica and iron oxide, respectively. The gloss factor for Al_2O_3 is -1.00 ; for SiO_2 is 0.376; and for Fe_2O_3 is -2.923 .

When the composition of a clay is such that $G = -0.24$ to -0.1337 the glaze is matt; when $G = -0.1337$ to 0 the glaze is semi matt; and when $G = 0$ to < 0.1576 the glaze is bright.

9. The glazes produced by clays of varying compositions were divided into 15 groups as follows: (1) Dark brown to black bright glazes, (2) mahogany bright glazes, (3) brown bright glazes, (4) light brown bright glazes, (5) white to tan bright glazes, (6) dark brown to black semi-matt glazes, (7) mahogany semi-matt glazes, (8) brown semi-matt glazes, (9) light brown semi-matt glazes, (10) white to tan semi-matt glazes, (11) dark brown to black matt glazes, (12) mahogany matt glazes, (13) brown matt glazes, (14) light brown matt glazes and (15) white to tan matt glazes.

10. Increasing the silica content of low silica clays increases the thickness of the resultant salt glaze as high as 600%.

11. Clays containing considerable iron oxide had a black casing of vitreous clay underneath the glaze which encased the entire test piece.

12. The geological age of a clay bears no close relation to the type of salt glaze it will take.

NOTE: In conclusion the writer wishes to acknowledge his indebtedness to Dr. E. W. Tillotson for helpful advice during the progress of the work and to the courtesy of The Patton Clay Manuf. Co., Patton, Pa., and The Pennsylvania Clay Products Co., West Winfield, Pa., at whose plants these tests were conducted.

WASHING TESTS OF GEORGIA CLAYS¹

BY R. T. STULL² AND G. A. BOLE³

ABSTRACT

The Whirlpool Classifier.—A device is described by which the impurity in a clay can be separated more efficiently than is possible by simple elutriation processes.

Washing Plants.—A semi-commercial plant used to wash 1000-lb. samples is described, together with a suggested plan for a commercial plant.

Beneficiation of Georgia Clays.—Results obtained on several Georgia sedimentary clays are given. The washed clays are reported free from grit and material producing specks in burned ware as well as improved in color, both in the raw and burned state.

Introduction

The amount of English china clay normally used in the United States prior to 1920 amounted approximately to $1\frac{1}{2}$ times the annual domestic production. The English china clay is used mostly in the production of the better grades of pottery, paper, and oil cloth.

The users of English china clay say that it is more dependable than the majority of domestic clays on account of its uniformity, a point which the American producers should strive to attain if they are to compete with the foreign product. In pottery it appears to give, as a rule, better color and working properties and produces a higher per cent of sound ware. In the paper and oilcloth industries, the English clay seems to give better spreading qualities and to produce less wear upon the machinery. These desirable properties of the English clays are, to a degree, due to their careful washing and blending.

An oilcloth manufacturer reports that it is only necessary to grind his spreading knives twice a week when using English clays, whereas it is necessary to grind them twice daily when using American clays. The principal objection to American clays, therefore, seems to be that they contain considerable "gritty" or abrasive material which, if removed, would give a more uniform product of better plasticity and working properties and in many cases, a whiter burning product.

The gritty material in kaolin may be composed of a number of different minerals, chief among which are quartz, mica, rutile, and partly weathered feldspar, besides iron bearing minerals detrimental to color.

Separation of Coarse Grit.—In the clay washing process where the separation is made by flowing the clay slip in troughs or sluices, considerable fine granular material and thin mica flakes are carried over with the clay, a large per cent of which passes through the screens. The degree of separation with respect to size of the particles depends upon the force

¹ Published by permission of the Director, Bureau of Mines. Work done in coöperation with the Central of Georgia Railway Co.

² Supervising Ceramist.

³ Superintendent, Ceramic Experiment Station.

of gravity acting against the carrying power of the water due to its velocity of flow.

Inasmuch as the force of gravity is constant, the degree of separation can be governed by regulating the velocity of flow. The fine granular material in settling carries down more or less clay substances even though the clay has been deflocculated and the quantity thus lost increases rapidly with the decrease in the velocity of flow and decrease in the size of particles settling. To remove the fine abrasive material passing the 120-mesh screen which causes excessive wear on paper and oilcloth machinery, it would be necessary to slow down the flow to such an extent that the loss of clay carried down with the grit would be excessive.

Separation of the Finer Grit.—Nearly everyone has observed on dissolving salts in a beaker of water by stirring with a glass rod, that upon removal of the stirring rod, the grains of undissolved salt will move rapidly in a spiral path toward the center of the beaker and concentrate in the form of a flat cone on the beaker bottom.

It was thought that this "center seeking" principle observed in the whirling liquid in the beaker might be adapted to the claywashing process for removing the fine grit and mica. The operating principle of the cyclone dust separator is somewhat similar.

Part I.—The Whirlpool Classifier

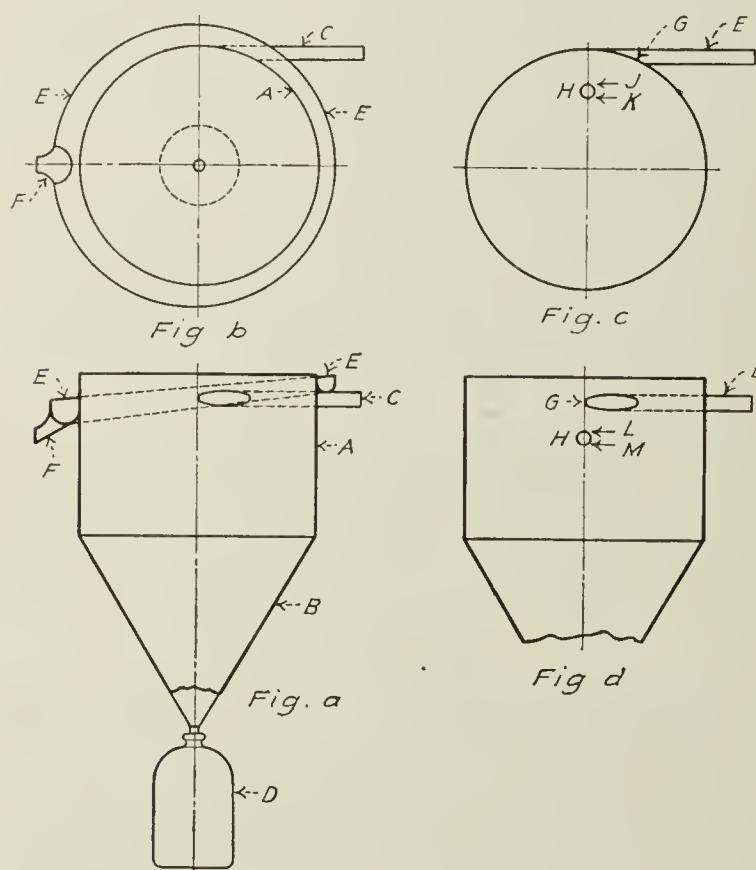
The Classifier.—The clay separator herein described differs from the air separator more particularly in that the conveying medium is water instead of air. The separation of the coarser from the fine and colloidal particles is effected by producing a whirlpool motion in the clay slip in a stationary cylindrical vessel. The separator has therefore been called the "Whirlpool Grit Separator" or the "Whirlpool Classifier."

Fig. 1a shows the elevation and Fig. 1b the plan of one of the first separators used in the preliminary experiments. The cylindrical portion *A* was 12 inches in diameter and 8 inches high. The height of the collecting cone *B* at the bottom was 10 inches. The cylindrical portion of the separator was provided with a tangential spout *C* near the top for the inflow of the clay slip. The clay slip, flowing in tangentially from a constant head, sets up a "whirlpool" motion, causing the coarser particles to be carried to the center and downward, where they are collected at the bottom of the cone in a connected flask *D*. The very fine clay particles float with the water out over the top into a trough or launder *E* and flow out the spout *F*.

Basic Principle of Whirlpool Classification.—To observe the path of travel of a particle, consider that the liquid in the separator Fig. 1c is made up of an infinite number of concentric rings. The liquid flowing in tangentially through the spout at *G* causes the different rings to rotate at different angular velocities. A ring of liquid near the wall of the can

has the highest angular velocity or r.p.m.¹ The angular velocity of each successive ring diminished toward the center of rotation due to the "slip-page" or lag effect of each successive ring.

Let H be a granular particle large enough to be acted upon by the differential of forces. Also let the arrows J and K , Fig. 1c, represent the magnitude of the forces of two liquid rings, produced by the different angular velocities. The force J acting upon the outer edge or point of H farthest



FIGS. 1a, b, c, d.—Whirlpool separator.

from the center of rotation is of greater magnitude than the force K acting on the point of H nearest the center of rotation. These unequal and parallel forces acting in the same direction on opposite sides of the particle H cause it to rotate in a horizontal plane.

The point about which the particle H rotates is not its center but a constantly changing point between its center and the center of rotation of the liquid rings. This off-center rotation of H , together with its forward movement, causes it to travel in a spiral path to the center of the cylinder. As

H travels from the point of inflow to the center, it is continuously passing from rings of higher to lower angular velocity. Its rate of travel, therefore, diminishes as it approaches the center of the cylinder.

At the same time that the unequal forces are crowding H toward the center of the cylinder, unequal and parallel forces are also acting upon it together with gravity, to force it downward.

Not only may we consider that the liquid with its suspended particles consists of an infinite number of concentric rings horizontally, but we may also consider that it is made up of an infinite number of discs or layers vertically, Fig. 1d. A disc of liquid opposite the inflow at G travels at the highest velocity and the velocity diminishes in each successive layer below, due also to the lag effect.

Since the disc of liquid on top of the particle H is rotating at a higher rate than the layer on its lower side, the force L acting on top of H is of greater magnitude than the force M acting on its lower side. These

¹ The liquid rings in contact with the wall of the separator are retarded by friction. Those of highest angular velocity are a short distance away from the wall.

nequal and parallel forces, therefore, cause H to rotate vertically about point below its center which causes it to travel downward, assisted of

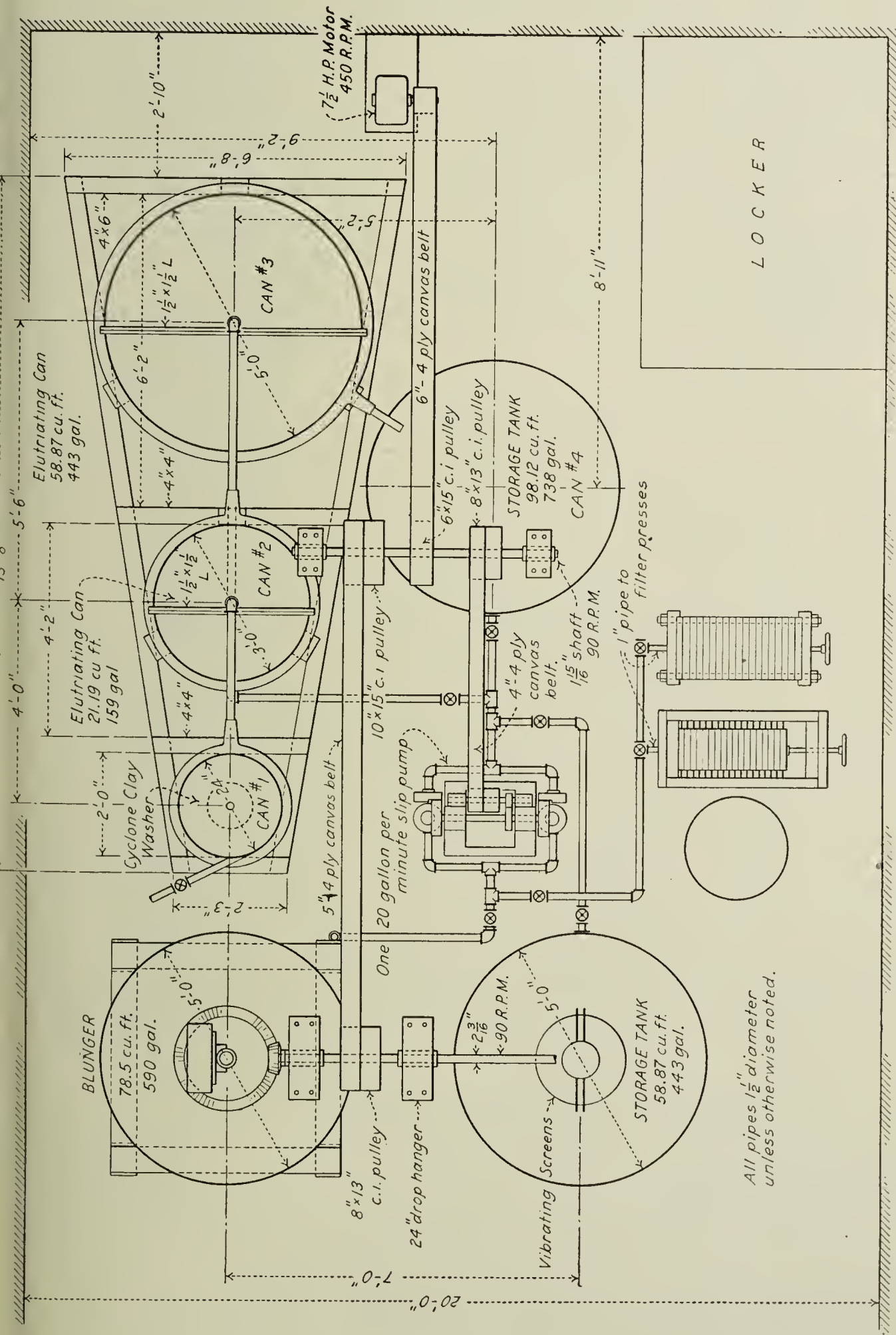


FIG. 2.—Plan, semi-commercial clay washer.

course by gravity. Its fall is rapid at first and decreases as it descends into layers of lower and lower r.p.m.

Large particles travel to the center and downward more rapidly than small ones because the differential of forces acting upon their opposite sides is greater. As the size of the particle diminishes, the difference between the magnitude of the forces acting upon it diminishes. As the diameter of the particle approaches zero, the difference in magnitude of the forces acting upon it approaches zero. However, before the theoretical zero size of particle is attained, a size occurs whose diameter is such that its center seeking force is over-balanced by the small centrifugal force as-

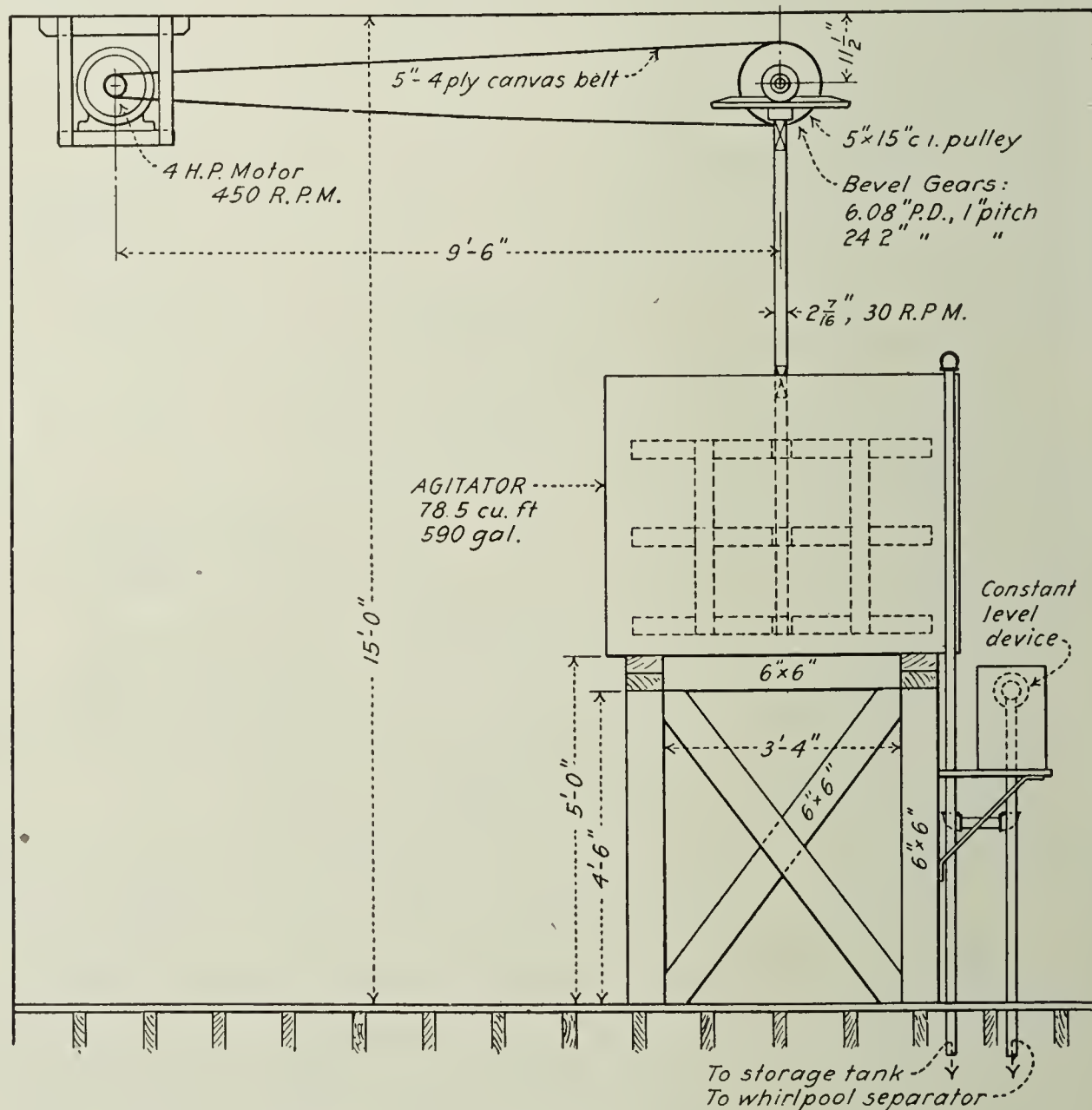


FIG. 3.—Elevation, semi-commercial clay washer.

sisted by the carrying power of the liquid. The particle, therefore, travels with the liquid and substantially as a part of it, and finally passes out over the top of the cylinder into the trough *E* and passes out of the spout *F*, Fig. 1a.

Experimental Test of Whirlpool Classifier.—Preliminary tests were made with 15-pound samples of Georgia kaolin previously washed at the mines. The clay was prepared in slip form consisting of 90 per cent water and 10 per cent clay by weight and deflocculated with caustic soda

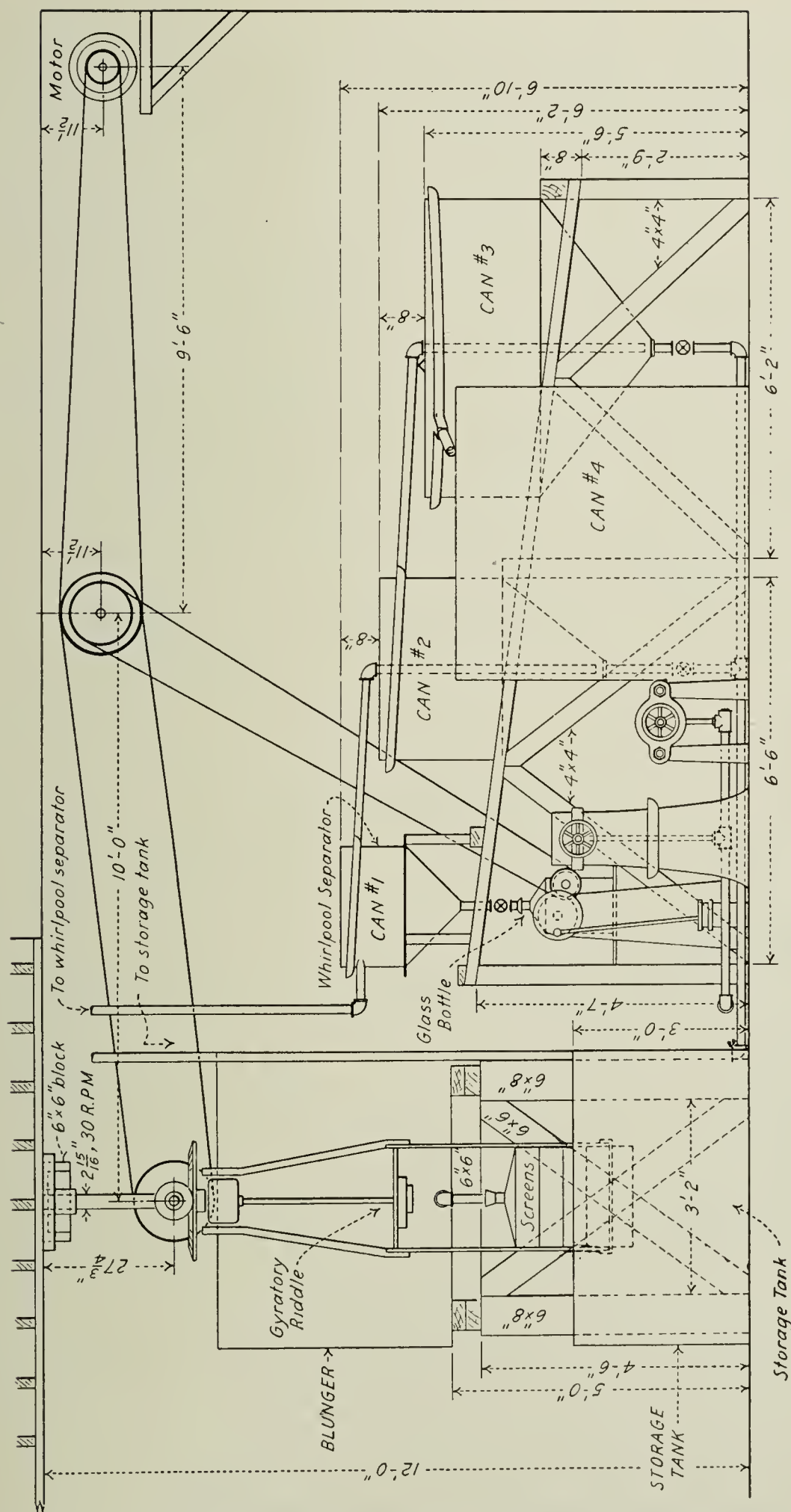
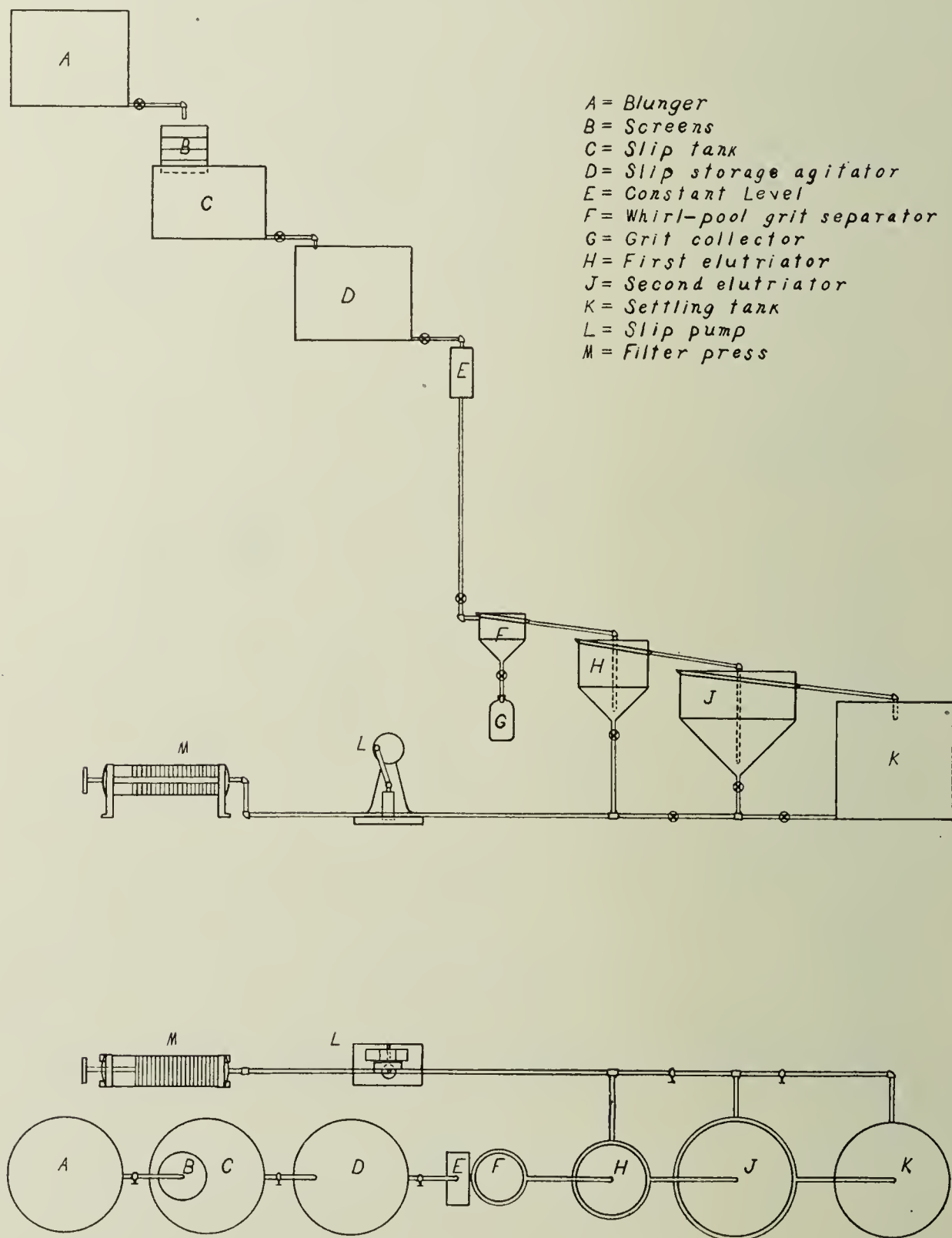


FIG. 4.—Elevation, semi-commercial clay washer. (See Fig. 3.)¹

The separator was first filled with clear water and the clay slip passed in from a constant level tank at an elevation of 15 feet, the inflow being regulated by a valve. After the clay slip had passed through, clear water was run through until the overflow became clear.

¹ Figs. 3 and 4 are part of the same elevation.

The grit collection in the flask was removed, dried and weighed. The average grit removed from five tests was 6.09%. This consisted principally of silica grains and mica with some coarse kaolin grains and fine brown particles of rutile.



FLOW SHEET, CLAY WASHER —

FIG. 5.—Conventional flow sheet.

Semi-Commercial Washing Plant.—The coöperation between the Bureau and the Central of Georgia Railway Company made it possible to try out the whirlpool grit separator on a semi-commercial scale. A

washing plant designed to take care of a thousand-pound batch was constructed, using the same principle as that described above. The blunger *A* was 4 feet in diameter and had a capacity of 600 gallons. The whirlpool separator *F* was 2 feet in diameter, and the two elutriators *H* and *J*, 3 and 5 feet, respectively. The settling tank *K* was 6 feet in diameter and had a capacity of approximately 1000 gallons. *L* is a pump capable of feeding the slip to the filter presses *M* at a pressure of 65 pounds. The plan and elevation of the set-up, drawn to scale, together with appropriate legends, is shown in Figs. 2, 3, and 4. A conventional flow sheet is shown in Fig. 5 to which the letters in the above description refer.

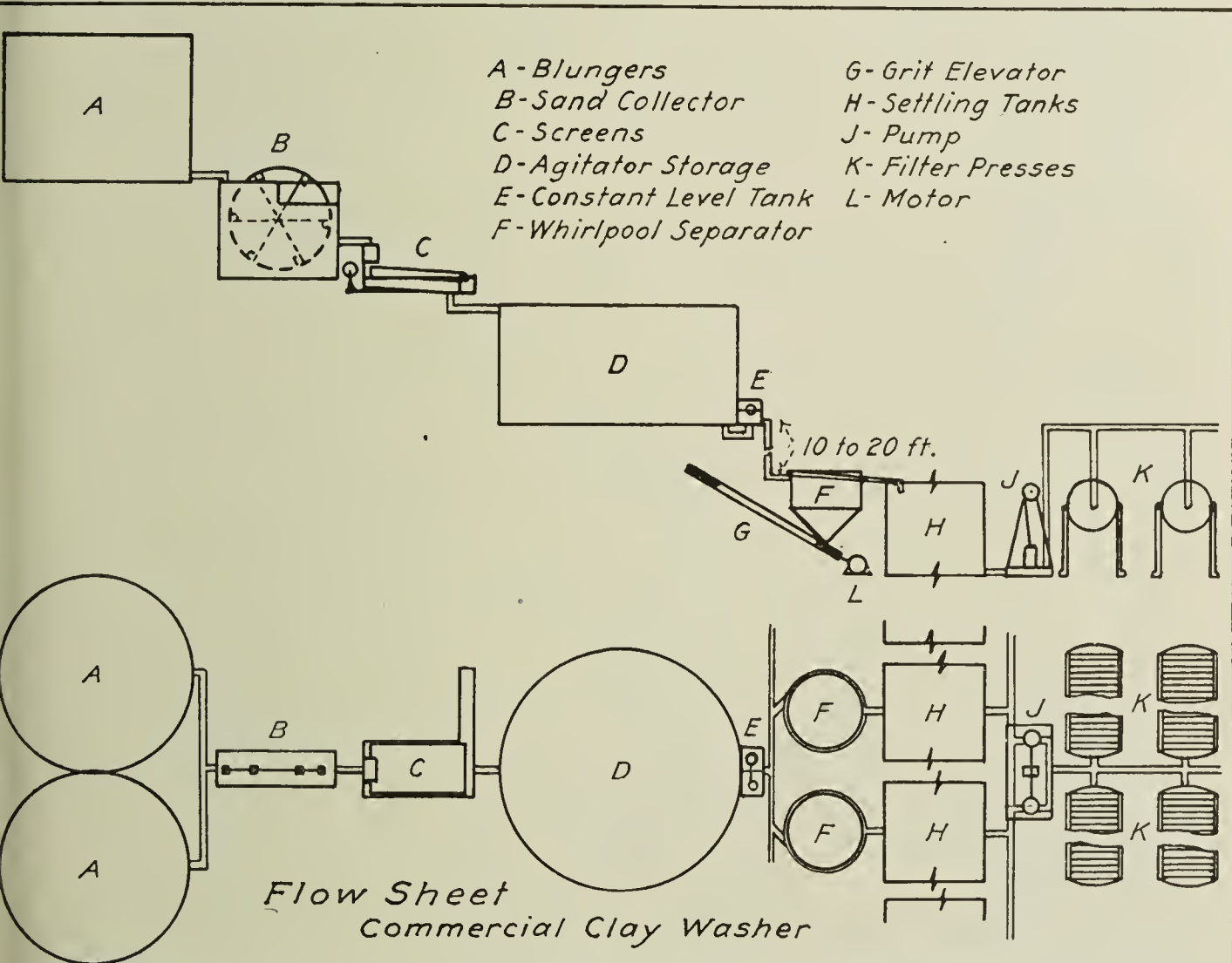
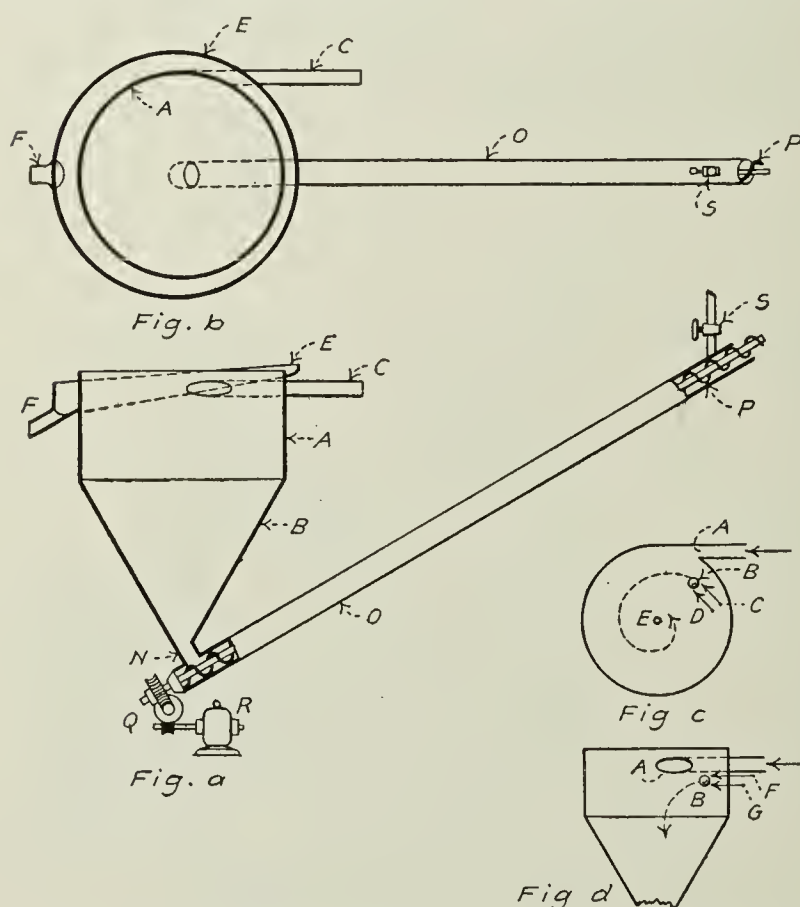


FIG. 6.

Since the capacity of the blunger was just about large enough to take care of 500 pounds of clay when blunged to a slip of 15% solids by weight, the slip, after being thoroughly blunged with the appropriate amount of electrolyte, was run through a nest of screens, suspended in a gyratory siddle and stored in tank *D* where it was agitated until an additional charge of 500 pounds was blunged and ready to be run through the washer. The valve leading from the agitator to the constant level tank *E* was then opened and the charge run through the washer at the rate of about 2.5 gallons per minute. When the slip was run, an attempt was made to get as much through the system as possible before starting the water for

washing. It was the aim to wash until the several cans were clear, but it was not possible in all cases on account of the limited capacity of the outfit. A large amount of experimentation proved that the rate at which the clay was run through the washer could be varied considerably without materially changing either the quantity (per cent) or quality of the recovery in the settling tank.

Suggested Commercial Plant.—A flow sheet for a commercial plant is suggested in diagrammatic form in Fig. 6. In the proposed outfit are two blungers *A* in order to make the operation continuous. The coarse grit is removed by the sand wheel *B*. From the sand trough the slip flows over the mechanically agitated hundred mesh screen *C* and into the agitator *D*. The flow into the whirlpool separators *F* is regulated by a constant level tank *E*. There is provision made for as many whirlpool



FIGS. 7a, b, c, d.—Whirlpool separator with grit elevator.

separators as the capacity may demand. Extra units may be added from time to time. The grit elevator *G* which is operated by the motor *L*, delivers the coarse material at the level of the overflow from *F* to a dump.

As many settling tanks *H* are provided for as the capacity may demand. The pumps *J* serve to deliver the concentrated slip to the filter presses *K*. Electrolyte is added to the blungers in order to float the clay, the amount being previously determined by laboratory tests. The slip is flocculated in the settling tanks by the addition of acid. Such an

outfit can be depended upon to deliver to the presses approximately 70% of the clay charged when Georgia sedimentary clays are being washed.

A detail drawing of the whirlpool classifier with grit elevator is shown in Fig. 7a, b, c, and d. The designs are the same as those in Fig. 1 with the exception that a grit elevator has been substituted for the glass bottle *D*. In Fig. 7a (*O*) is a metal tube the length and diameter of which will vary with the capacity of plant and the clay being washed.

A motor (*R*) driven worm (*P*) is operated at such a speed as to remove the grit from the cone of the classifier. By proper gears (*Q*) the rate at which the material will be removed can be controlled. Wash water

is admitted at (S) in order to wash the ascending column free from clay.

The capacity of a classifier in pounds per hour figured on a dry basis, is governed by the density of the slip and the rate at which it is delivered.

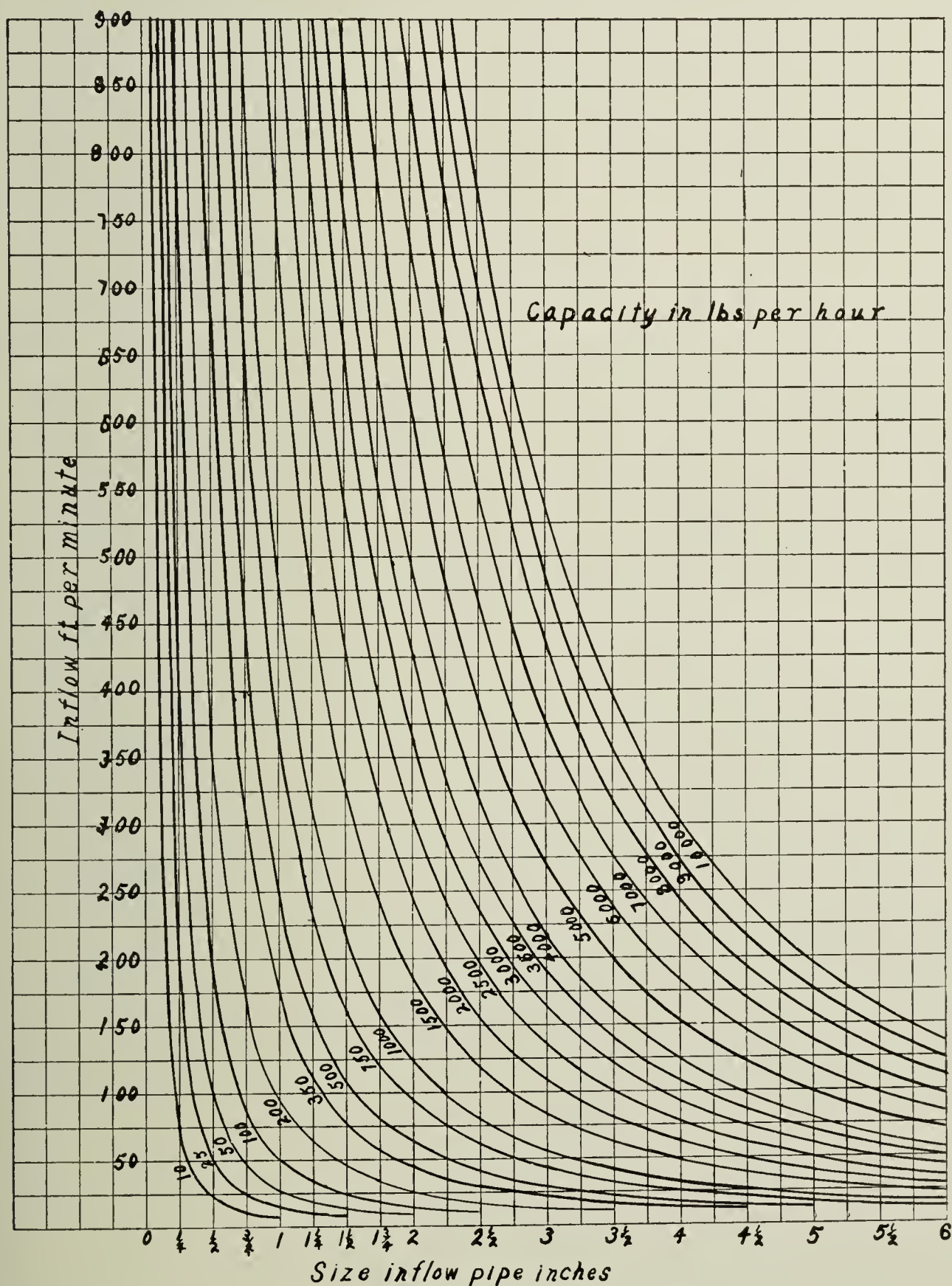


FIG. 8.—Capacity of grit separator.

In Fig. 8 diameter of inflow pipe is plotted against rate of flow. The figures are based on a slip containing 10% clay. A rough idea of the dimensions required for a classifier of desired capacity can be gained from the curves.

Part II.—The Washing of Georgia Clays

Deflocculation.—The quantity of electrolyte necessary to be added to the slip in order to deflocculate the clay and later to flocculate it, using distilled water, was determined by both viscosity and settle tests. These methods have been described so often in the literature that any further description is not thought necessary. If the reader is not familiar with the details of the methods used, he is referred to Bleininger¹ and Sproat.²

The Georgia sedimentary clays are not uniform in their behavior toward electrolytes. This is to be expected as their colloidality varies

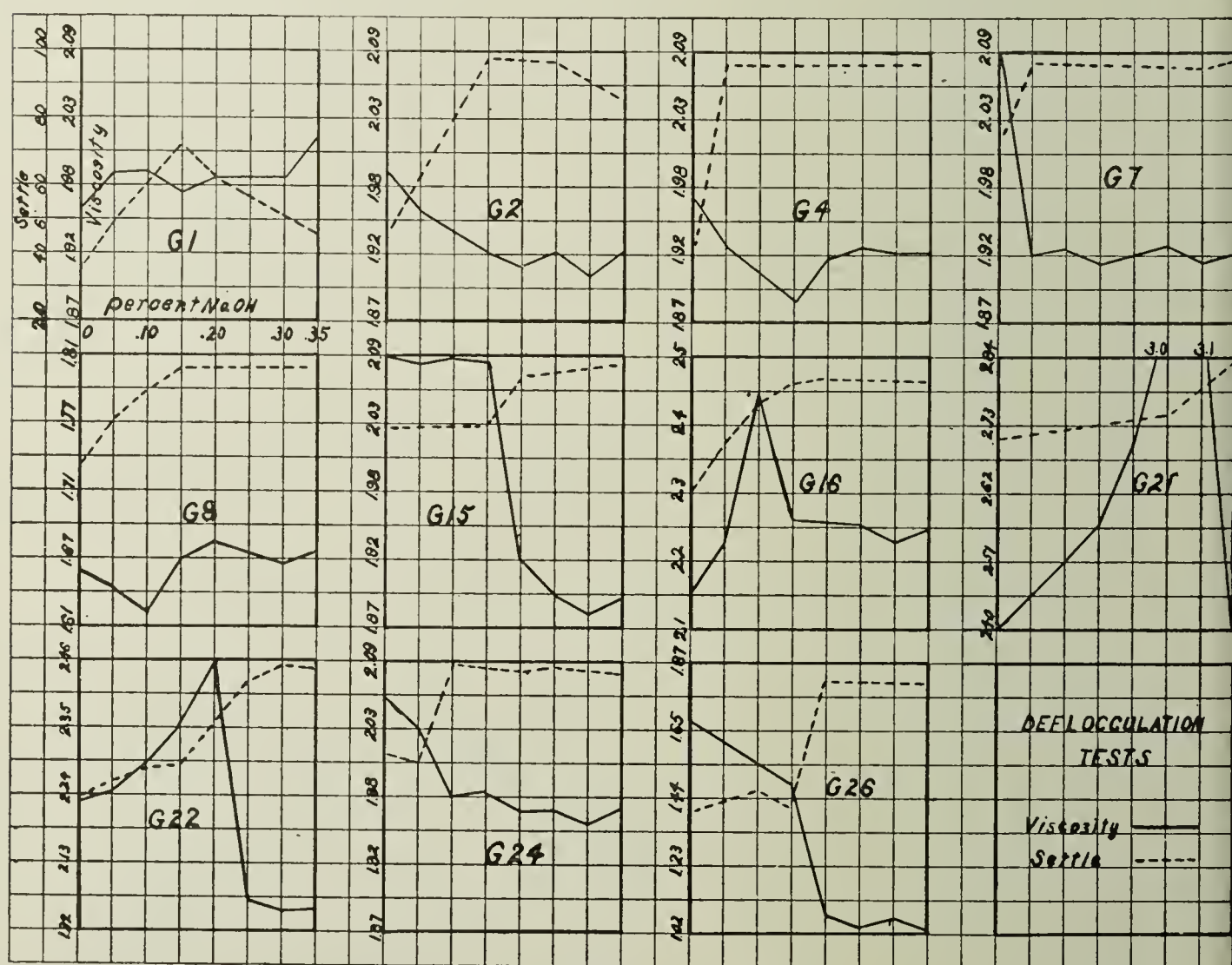


FIG. 9.—Deflocculation and settle curves.

greatly. Some of the clays were not affected at all by small amounts of either base or acid, while others were very sensitive to electrolytes of both classes. Settle methods were hardly so satisfactory as viscosity determinations for some of the clays, as a small amount of a highly colloidal material stays in suspension much longer than the body of the material, thus giving misleading values.

The quantity of electrolyte required varies enormously with the dif-

¹ *Trans. Amer. Ceram. Soc.*, **14**, 827 (1912).

² U. S. Bureau of Mines, *Bull.* **128**.

ferent clays. In a few cases, the clays are so highly deflocculated by blunging with distilled water that the addition of alkali distinctly raises the viscosity. One of the clays was especially difficult to handle because of the fact that neither acid nor base had the slightest affect upon it.

Sodium hydroxide was used as the deflocculant and acetic acid as the coagulant. A comparison of the viscosity and settle tests on a few of the clays, using distilled water, is shown in Fig. 9.

Results of Washing.—It was not in all cases possible to tell from preliminary tests whether a clay would wash to a good white either raw or burned, so all the clays that gave any promise of being satisfactory for either the filler or whiteware trade were run through the washer. A small sample of the overflow was dewatered in each case and if the raw and fired clay proved not at all satisfactory as to color all but a small sample of the slip was run into the sewer. If the color tests proved satisfactory the entire charge was dewatered.

Eighteen samples proved to be suited to the filler trade after washing. Three hundred-pound samples of each of these clays were sent to the Southern Station of the U. S. Bureau of Mines to be later tried out commercially in the filler trades. A report on this phase of the work will be made at a later date.

The fire tests showed that seven of the washed samples burned to a sufficiently good white to justify trying them out in the whiteware trade. The results of tests made on these clays will be reported in the next of this series of articles.

The burned color of most of the clays was greatly improved by washing. However, two of the number burned to a poorer white than the crude clay. The degree to which any clay can be purified by this method of washing depends upon two factors, (1) the degree to which the clay will disperse, and (2) the specific gravity of the dispersed particles. If the impurity in a clay is of a low specific gravity or if it is in a colloidal state of subdivision, or a combination of the two, it will be carried over into the settling tank. The whirlpool classifier seems to separate mica flakes more efficiently than a simple flotation process, due to a sort of diving effect brought about by the unbalanced forces acting on different parts of the flake. This effect causes the flakes to concentrate at the bottom and they are removed with the grit.

Dewatering.—The more finely divided clays filtered so slowly that methods other than filter pressing were tried. The thickened slip was run into large plaster of Paris troughs and dried. Heat was applied and fans used in an endeavor to hasten the evaporation of the water. The method was slow at best but gave better results on two of the more finely divided clays than did filter pressing.

A barrel of slip was run through a Dorr thickener and brought up to

a solid content of 32%, after which it was dewatered in a continuous disc vacuum filter. The cake contained 37% moisture as against 32 per cent in a pressure filter. The results obtained on this particular clay would seem to indicate that the method could be made an economic success.

The utility of a vacuum filter varies enormously with different clays. The more finely divided the clay, the slower the operation. If a cake one-eighth inch thick can be built up without slowing up the operation unduly, the system stands a chance of success. The dewatering of these clays will be taken up in a later paper.

Chemical and Microscopic Analysis of the Separates Obtained

In order to gain some idea of the efficiency of the washing process, chemical and microscopic analyses were made on each of the separates in the case of two of the clays selected for the whiteware tests. In the following table are shown the results of chemical analysis on one of these clays (G-7).

	Crude	Grit	Can 1	Can 2	Can 3	Can 4
Loss on						
Ignition	13.55	11.42	13.06	13.30	13.55	13.47
SiO ₂	44.25	42.29	45.49	44.94	45.10	45.26
Al ₂ O ₃	38.64	36.28	37.50	37.71	37.91	38.74
Fe ₂ O ₃	1.45	3.45	1.35	1.39	1.27	1.32
TiO ₂	1.62	5.79	1.86	2.15	1.75	.95
P ₂ O ₅	.05	.02	.07	.05	.05	.02
CaO	.17	.22	.05	.17	.16	.25
MgO	.10	.36	.11	.12	.08	.02
K ₂ O	.13	.31	.39	.41	.26	.09
Na ₂ O	.29	.33	.30	.20	.15	.25
Sulphur	.02	.02	.01	.01	.01	.01
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	100.27	100.49	100.19	100.45	100.29	100.38
TiO ₂ + Fe ₂ O ₃	3.07	9.24	3.21	3.54	3.02	2.27
Accessory						
Minerals	3.83	10.50	4.14	4.50	3.73	2.91

Clay G-7 showed the following screen and elutriation separates together with microscopic examination:

Separates	Percentage	Microscopic examination
On No. 8 screen	.195	The material on the various screens varied in size of grain rather than in the minerals present, consisting largely of a fine grained mineral having an index of refraction of 1.57 (probably bauxitic kaolinite). The accessory minerals included bauxite, quartz, zircon and black iron oxide.
On No. 20 screen	.310	
On No. 65 screen	.680	
On No. 100 screen	.242	
On No. 150 screen	.292	
Grit separate (bottle)	1.072	The most abundant mineral is iron-stained secondary kaolinite. A rather large amount of primary kaolinite is also present and the following in large amounts: quartz, zircon, rutile, biotite and black iron oxide. Tourmaline was found as a rare constituent.

Can No. 1 (whirlpool)	2.043	The most abundant constituent is secondary kaolinite. A rather large amount of primary kaolinite is also present. The accessory minerals occur in rather large quantities in this separate, zircon and muscovite predominate. A rather large amount of a black mineral, probably iron oxide, is present. Rutile, quartz and biotite occur in considerable quantities. A small amount of tourmaline is also found.
Can No. 2	1.950	This separate consists largely of iron stained secondary kaolinite. A rather large amount of primary kaolinite is also present. Considerable zircon, muscovite, quartz and rutile were found. Of these accessory minerals, muscovite predominated. A small amount of biotite and tourmaline was rarely found.
Can No. 3	10.400	This separate consists almost entirely of primary and secondary kaolinite. The secondary is iron stained and imparts a brown color to the clay. Only small amounts of fine-grained accessory minerals are present. Muscovite was found in the greatest quantity. Quartz, zircon, rutile, biotite and iron oxide were found in smaller amounts.
Can No. 4 (settle tank)	81.816	This separate consists almost entirely of primary and secondary kaolinite, the secondary kaolinite being much in excess of the primary. The secondary kaolinite is iron stained and imparts a slight brown color to the clay. Only very small amounts of fine-grained accessory minerals are present. Very small amounts of muscovite, quartz, zircon, rutile and black iron oxide composed the accessory minerals that were present.

COMPARATIVE CHEMICAL ANALYSES OF WASHED AND UNWASHED CLAY

	G-1		G-2		G-4		G-9	
	Crude	Washed	Crude	Washed	Crude	Washed	Crude	Washed
Ignition								
Loss	12.92	13.11	19.74	19.18		13.91	12.00	13.54
SiO ₂	46.52	46.76	31.98	32.51		45.42	51.16	45.22
Al ₂ O ₃	36.87	36.83	45.73	46.29		38.86	33.84	38.31
Fe ₂ O ₃	1.47	1.44	.66	.54		.60	1.35	1.20
TiO ₂	.77	1.36	1.68	1.40		1.36	1.16	1.44
P ₂ O ₅	.05	.06	.07	.04		.03	.09	.09
CaO	.80	.15	.11	.14		.02	.30	.04
MgO	.30	.36	.17	.02		.12	.05	.13
K ₂ O	.43	.19	.00	.00		.00	.18	.17
Na ₂ O	.00	.00	.00	.11		.00	.12	.00
Sulphur	.02	.02	.04	.04		.02	.10	.02
	G-15		G-16		G-21		G-22	
	Crude	Washed	Crude	Washed	Crude	Washed	Crude	Washed
Ignition								
Loss	13.90	13.72	13.28	13.28	11.75	14.50	14.08	14.02
SiO ₂	43.57	45.15	45.22	45.96	43.77	43.75	44.42	44.62
Al ₂ O ₃	39.76	38.94	38.86	37.93	38.31	38.46	39.34	39.03
Fe ₂ O ₃	.96	.72	1.02	.87	1.47	1.56	.60	.54

COMPARATIVE CHEMICAL ANALYSES OF WASHED AND UNWASHED CLAY (Continued)

	G-15		G-16		G-21		G-22	
	Crude	Washed	Crude	Washed	Crude	Washed	Crude	Washed
TiO ₂	1.17	1.20	1.03	1.52	1.04	1.32	1.64	1.72
P ₂ O ₅	.04	.03	.07	.06	.04	.06	.07	.07
CaO	.24	.11	.21	.05	.25	.02	.16	.08
MgO	.11	.02	.10	.26	.07	.08	.04	.10
K ₂ O	.16	.25	.51	.34	.17	.22	.00	.00
Na ₂ O	.38	.00	.08	.04	.13	.19	.02	.00
Sulphur	.15	.03	.02	.04	.16	.18	.06	.03

	Crude	G-24	Washed	Crude	G-26	Washed
Ignition						
Loss	13.35		13.90	13.20		13.76
SiO ₂	48.23		45.35	45.27		44.99
Al ₂ O ₃	35.60		37.23	38.78		38.62
Fe ₂ O ₃	1.29		1.50	.81		.75
TiO ₂	1.60		1.56	1.16		1.52
P ₂ O ₅	.02		.02	.14		.13
CaO	.07		.16	.13		.07
MgO	.05		.07	.07		.17
K ₂ O	.00		.14	.02		.18
Na ₂ O	.04		.14	.49		.13
Sulphur	.01		.07	.01		.07

MECHANICAL SEPARATIONS OF WASHED CLAY

	G-2	G-4	G-15	G-16	G-24	G-26
On No. 8 screen	.20	...	.089	...	.387	...
On No. 20 screen	.50	...	.039	...	.268	...
On No. 65 screen	1.30	.635	.429	.20	1.362	.07
On No. 100 screen	.75	.185	.420	.20	1.100	.26
On No. 150 screen	.55	.140	...	...	...	...
Grit separate						
(bottle)	4.00	3.220	2.778	1.20	4.800	1.09
Can No. 1	5.00	2.190	1.857	1.50	...	1.24
Can No. 2	7.00	5.300	5.034	4.20	1.000	1.46
Can No. 3	9.00	17.930	8.364	17.20	8.900	18.80
Can No. 4						
(settle tank)	71.70	70.400	80.990	75.50	82.183	77.08
	100.00	100.00	100.00	100.00	100.00	100.00

Description of the Washed Georgia Clays

Due to the variation of kind and amount of electrolytes in the Columbus city water, which was used for the semi-commercial tests, the results plotted in the graphs (Fig. 9) were not a safe guide from which to figure the amount of NaOH which should be added for deflocculation during the large batch washing as the results there plotted were obtained using distilled water. The viscosity of each clay is represented by a solid line and the amount remaining in suspension, termed "settle," by a dotted line.

Clay G-1.—Five hundred pounds of this clay were blunged and washed as described previously, using 0.24% NaOH. It was found necessary to carry on the blunging for 8 hours before the clay was completely disintegrated and ready to be put through the washer. The speed at which the washer was run was varied between 2 and 3 gallons per minute. Samples were collected during the several speeds after which color pats were made up and burned. As there was no variation in color apparent, it seemed safe to assume that the washer could be safely operated between these two limits. The color of the washed clay fired to cone 12 was a light gray and it gave little promise for use in the whiteware industry. Due to the finely divided character of the clay, some difficulty was experienced in filtering.

Clay G-2.—One thousand pounds of this clay were blunged using 0.24% NaOH. The raw clay was a good white color but contained a considerable quantity of bauxite nodules. The clay blunged very readily after deflocculation. In many respects this is a very peculiar clay as the chemical analysis shows it to be bauxitic in nature. In spite of this, however, it showed little more tendency to shrink during drying and burning than did the typical kaolins and exhibited other excellent working properties. Sedimentation was quite rapid, leaving a sticky residue in the bottom of the blunger which was difficult to remove during subsequent washing. On the addition of acid, the clay settled rapidly to a dense slip from which the water could easily be decanted. This clay was especially easy to filter press. The washed clay burned to a good white as did also a porcelain body containing 30%.

Clay G-4.—A one thousand pound batch of this clay was also blunged using 0.36% NaOH. The color of the raw clay was a good white but contained considerable material in the form of black specks. It slaked with difficulty and blunged slowly, 10 hours being required for the operation. A number of pebbles settled on the bottom of the blunger. Upon the addition of acid, the clay settled more slowly than did G-2 and formed a less dense slip, filtering was therefore somewhat slower. The washed clay burned to a good white and when made into a porcelain body the color was only slightly inferior to that of G-2.

Clay G-7.—A batch of one thousand pounds was blunged using .25% NaOH. The color in the raw state was only a fair white—microscopic examination showed it to be badly iron stained, only a portion of the stain was removed during washing. It blunged and filtered easily. The fire tests showed the color to be inferior to that of G-2 and G-4.

Clay G-9.—One thousand pounds were blunged using .20% NaOH. The color in the raw state was only a fair white—macroscopic examination showed it to contain many black specks. The clay blunged easily but filtered slowly. A sticky sediment was deposited in the bottom of the

blunger which was removed with difficulty. The fire tests of the washed clay were inferior in color to that of the raw clay, which fact seemed to be due to a colloidal iron. The color tests were so unsatisfactory that the clay was not tried out in the whiteware industry.

Clay G-15.—One thousand pounds were blunged and .3% NaOH used. The color of the clay in the raw state was a good white. It slaked readily thus cutting down the blunging time to 6 hours. No difficulty whatever was encountered during the washing. Due to the finely divided condition of the clay, filtering was somewhat slower than that of G-2. The fire tests gave a good white color which was comparable to G-4.

Clay G-16.—One thousand pounds of this clay were also blunged. This clay contains a little grit and was of an exceptionally good white color. Color samples of the crude clay burned to a good white but showed some black specks. No residue remained on screens No. 8 or No. 20. As indicated by the viscosity tests, this clay could be put into a high state of dispersion without the use of electrolyte. The clay blunged very easily and left little residue in the blunger. A predetermined quantity of acid was used to flocculate the clay. It settled rapidly and filtered very easily. The washed clay and porcelain bodies made from it burned to an excellent white, free from specks.

Clay G-21.—The same amount (1,000 pounds) of this clay was blunged. The color in the raw state was only fair. It blunged easily, was very finely divided, and fire tests showed the washed clay to be very little improved in color by operation. Since the clay gave no promise in the whiteware industry, only a small portion of it was filter pressed.

Clay G-22.—One thousand pounds were blunged using .3% NaOH for deflocculation. The crude clay burned to a poor white, it slaked and blunged fairly easily but settled very slowly upon the addition of acid. As the fire tests on the washed clay were unsatisfactory, only a portion of the batch was dewatered. Due to the extremely fine subdivision of the clay, filter pressing was exceedingly slow.

Clay G-24.—One thousand pounds were also blunged using .3% NaOH. This was the hardest clay to filter due to very finely divided material. It blunged very rapidly and a very sticky sediment settled in the blunger. The fire tests showed it to be somewhat better than G-22 but not sufficiently to justify trying out in whiteware practice.

Clay G-26.—The same amount of this clay was blunged using .25% NaOH. The color in the raw state was a fair white and burned to a good white. It slaked readily and no special difficulty was encountered during the washing. It filtered easily, comparing in this respect to G-2.

Discussion of Results

All the clays with the exception of G-22 and G-24 gave a better color

after washing than did the crude clays. These two clays exhibited a phenomenon similar to blue stoning. Many of the clays burned to a good white at cone 4 but developed a decided cream color at cone 12.

The color to which these clays will burn at cone 12 depends largely upon the ratio of the titanium and iron present. If the iron was low (.50%) and the titanium high (1.50%) or vice versa, the clay in most cases burned to a fair white. If the same total of iron and titanium was present, but each to the extent of 1%, the color was in every case poor. It is very probable that a titanate of iron is formed at the higher temperatures and causes the brownish tinge to which some of these clays burn above cone 8.

The washed clays containing more than 2% of titanium plus iron oxide failed to give a good color when fired to cone 12. The one exception was G-16.

The percentage of iron oxide found by chemical analysis is not so important in producing a variation from white as the form in which it is present. One of the clays which contained only .90% of iron and low titanium, developed a creamish tinge at cone 4, due to the fact that the iron was present as a stain on the kaolinite grains and was not removed by washing.

Conclusions

Based on data obtained during the investigation (a) it would seem that the Georgia sedimentary clays can be washed entirely free from dark burning material that caused specks in whiteware made from them; (b) that with proper blending and adequate storage space a uniform product can be put on the market; (c) that the burning color of the clays can be improved except in the case of those clays which contain their impurities in the form of colloidal material or stain on the kaolinite grains. This was the case with only two of the white clays investigated.

EFFECT OF GROG ADDITIONS ON FIRE RESISTANCE OF HOLLOW TILE¹

BY HARRY D. FOSTER

ABSTRACT

This paper mentions the general character of the investigation of the fire resistance of hollow tile and gives the results of only one phase of the work. A brief description of the test apparatus and the test method is given. Tests of three kinds of tile containing varying amounts of grog additions are described. These panels withstood the test for periods ranging from 20 minutes to six hours or more, the time varying indirectly with the grog content. It is concluded that the small grog additions which can be conveniently made in manufacturing practice have no effect, but that additions of five per cent or more will materially decrease the fire resistance of hollow tile.

The investigation of the fire-resisting and related properties of hollow building tile that is being conducted at the Bureau of Standards in co-operation with the Hollow Building Tile Association, consists of a series of tests of representative commercial load-bearing tile and also tests of tile embodying certain features intended as possible means of increasing fire-resisting properties. In the series here reported, the effect of additions of small percentages of grog (broken tile) to the tile clay was determined. Tests of tile from three different clays each containing no grog and 2½, 5 and 10% were made.

The necessary 8 x 12 x 12 6-cell load bearing tile were donated by three manufacturers. They were made according to the usual routine except for the varying grog additions to the raw clay.

One of the three kinds of tile used in these tests was a typical shale. The manufacturer reported that his raw material was taken by means of a steam shovel from the open bank which had a face of 40 feet, the lower 10 feet being a medium hard blue shale, the next 20 feet, an olive colored shale not so hard as the blue and the balance of the bank, the olive shale more or less weathered. The second series of tile was made from an Ohio fire clay known as the No. 6 vein of fire clay found with the No. 6 vein of coal. The third series was made from a shale and fire clay mixture. This manufacturer reported that his raw material was obtained by means of a shale planer working on twenty-five foot face. The top 22 feet consists of a soft carboniferous shale and the lower 3 feet of a hard material, which, although not a true soapstone in the geological sense, is known in that part of the country as a soapstone. This formation overlies a vein of coal which in turn overlies a six to twelve foot vein of No. 2 fire clay. This clay is dug separately and is mixed with the shale in the grinding process. The grog used was in all cases kiln refuse or broken ware crushed to pass the same screens used for the raw material.

¹ Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

All of the tile in each series were fired in various places in the same kiln. In this way tile representative of commercial ware were obtained and all factors contingent with laboratory work were avoided.

The test panels were laid up by an experienced mason working on contract basis. In order to duplicate prevailing conditions of practice the mason was allowed to use the mortar which he would normally use on an outside job. He chose a mortar of one part (by volume) of Portland cement, one part of lime and four parts of sand. After having made this choice the mortar was held to this proportion, the materials for each batch being accurately measured.

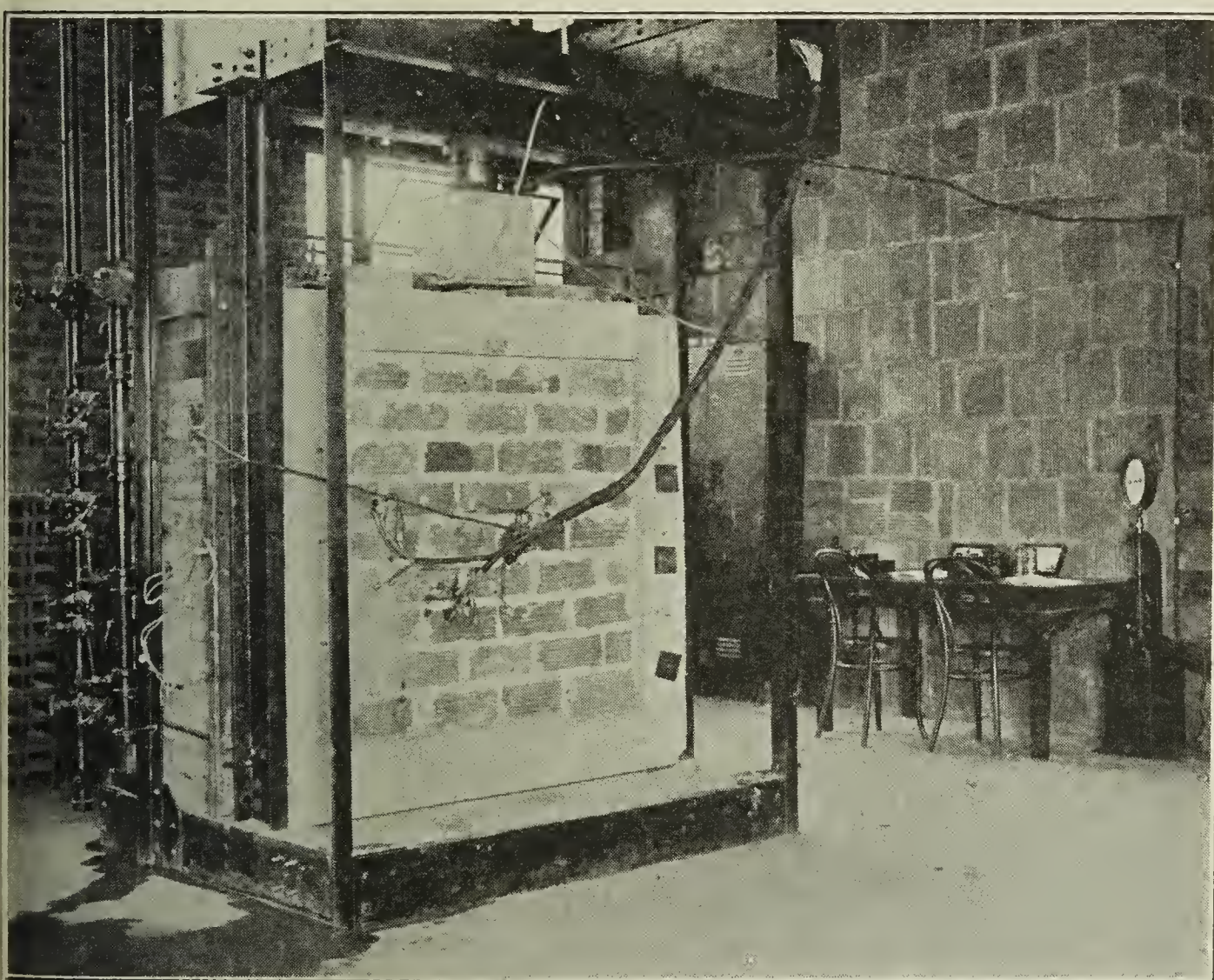


FIG. 1.—Testing furnace with panel prepared for testing.

All of the panels were aged 30 days before being tested. As these panels were built in the laboratory and during the summer, the best drying season of the year, it is believed that this aging period was ample.

The equipment necessary for conducting these tests consists of panel frames and crane for handling the test panels, a furnace for making the exposure, a restraining frame with hydraulic jack for loading the test panels, and a thermocouple installation for furnace control and for obtaining temperatures of the test panel.

Fifteen frames for holding test panels have been provided. Ten of these were built with their top member detachable, permitting loading of the panels. The remaining five were built solid so that the panel can be tested under restraint thus simulating a partition panel in buildings of fire-resisting construction.

The rear and two sides of the furnace (Fig. 1) are of brick construction, the front being closed by the test panel giving a combustion chamber two feet deep. Vent holes are placed in the crown of the furnace. The fuel used is gas taken from the city mains. By proper operation a temperature variation between different portions of the chamber of less than 20°C can be had except during the first half hour of the test.

The restraining frame is made of a heavy I-beam connected to the bottom member of the panel frame by channels serving as tension members.

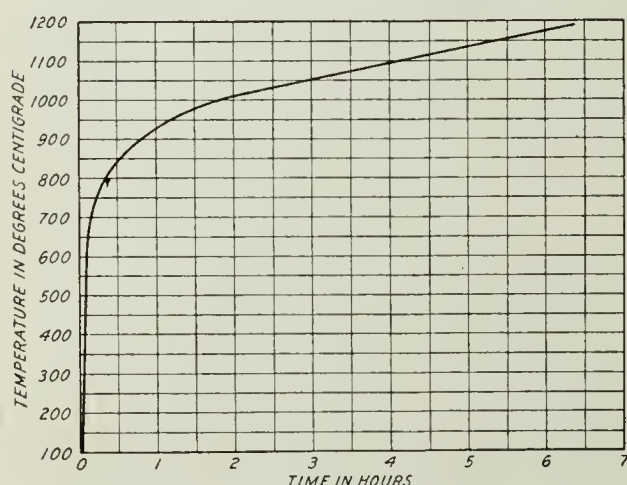


FIG. 2.—Time-temperature reference curve followed during fire tests.

The load is applied by means of a calibrated hydraulic jack placed between this I-beam and the top member of the test panel frame.

All temperature measurements are made by the thermo-electric method. Six couples are used to measure the furnace temperature and three couples symmetrically arranged about the center of the test panel were placed in each set of cells of the wall. Three couples, of very fine wire, were similarly placed on the

unexposed side of the test panel.

The material used in the couples is also used in the lead wires to the cold junction box (Fig. 1) which is kept at 0°C thus eliminating cold junction corrections.

A cathetometer mounted on a solid pier placed in front of the furnace is provided for measuring the vertical expansion of the test panel. Deflections are obtained by measuring from fine weighted wires attached to and stretched across the front of the panel frame.

The panels tested in the series under consideration were subjected to a constant working load and fire exposure increasing according to a predetermined time-temperature relation until failure occurred, with six hours as the limit of the fire exposure. The working load used in the tests was 120 pounds per square inch of gross bearing area. The time-temperature reference curve used is shown in Figure 2, and is the same as that now generally used in American fire test practice.

An accurate record was kept of the character of the fire and its effect on the test panel during all stages of the test. After the panel had cooled

It was torn out and notes on its general condition and the condition of each individual block were taken. Photographs were also taken of all panels after the test and a few typical panels before the test.

The period of time which a load-bearing wall is able to carry its load and hold back the fire and the salvage value of the wall after the fire, or in

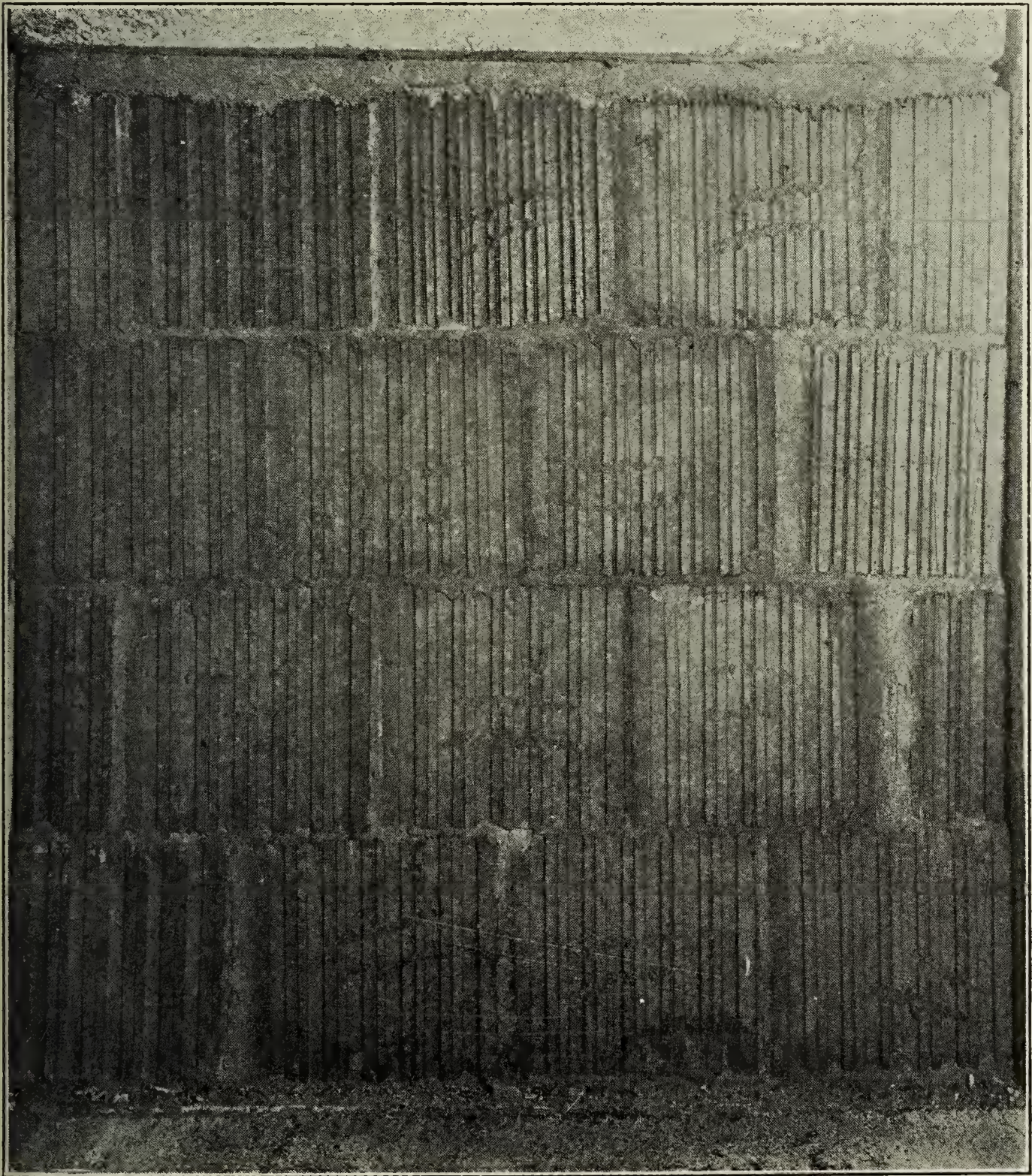


Fig. 3.—Exposed side of fire clay panel containing $2\frac{1}{2}\%$ of grog, after the fire test.

base fire-resistive interior construction is used, the extent of replacement necessary, serve as a criterion of the fire resistance of the panel being tested.

The panels of this series were able to carry their load from 20 minutes to 6 hours or more as follows:—

PERCENTAGES OF GROG ADDITIONS

	0	2½	5	10
Shale tile	6 hrs.	6 hrs.	4 hrs. 32 mins.	3 hrs. 47 mins.
Fire clay tile	6	6	4 02	3 17
Shale and fire clay tile		6	4 50	20

Typical illustrations of the effect of the grog on the fire resistance are shown in figures 3 and 4. Figure 3 shows the exposed side of the fire clay

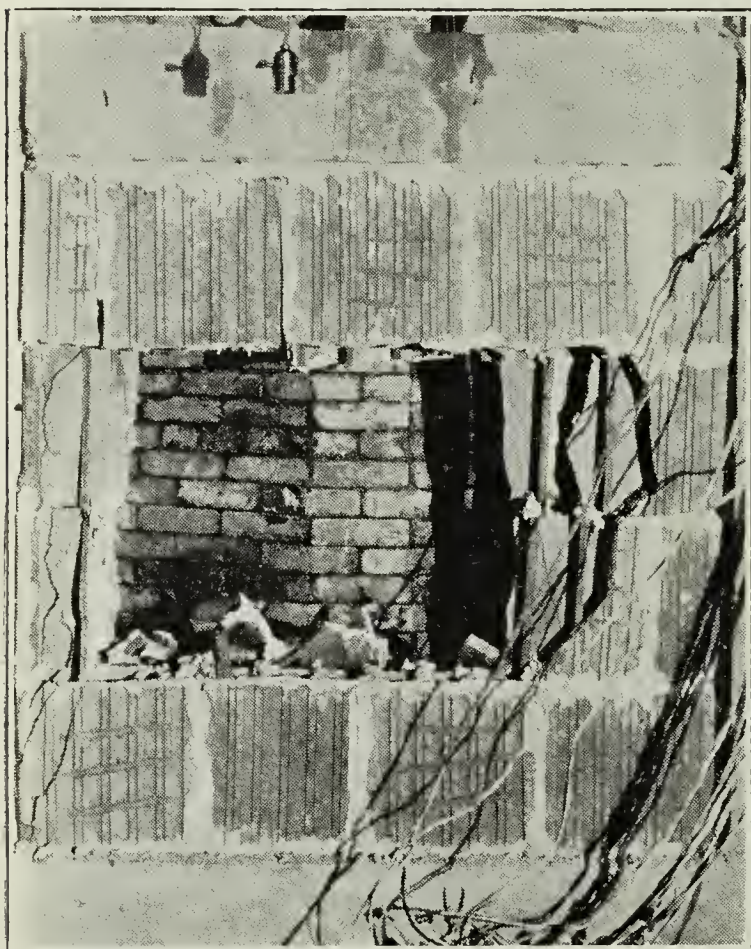


FIG. 4.—Fire clay panel containing 10% of grog, after fire test.

panel containing 2½% of grog after the six-hour fire exposure. This photograph indicates that few fire effects developed during the tests. A close inspection of the wall showed that a number of the fire-side shells were loosened to such an extent that they could be easily pulled away. No cracks were found beyond the center web of the tile. Figure 4 shows the unexposed side of the fire clay panel containing 10 per cent grog which failed under its working load after a fire exposure of 3 hours and 17 minutes.

Examinations under the microscope of fractures of tile containing grog disclose very minute cracks, probably from drying and burning shrinkage, radiating from the grog particles into the clay matrix. These fine cracks may be responsible for the early cracking of the tile body.

From the results of these fire tests it can be concluded that the small grog additions which can be conveniently made in manufacturing practice have no effect but that additions of 5% or more will materially decrease the fire resistance of hollow tile.

REQUIREMENTS OF REFRACTORIES FOR ELECTRIC FURNACES¹

BY CLYDE E. WILLIAMS

ABSTRACT

This article is essentially a survey, giving, however, not generalized statements, but a definite discussion of the refractories problems now existing in the important electric furnace processes. After summarizing some of the general refractory requirements of electric furnace work, the author discusses the specific conditions and refractory requirements in steel, iron, and non-ferrous metal melting, smelting furnaces for producing iron, ferro-alloys and calcium carbide, and in furnaces for melting refractory materials. The article closes with a summary of outstanding present developments.

Varied conditions probably make an ideal, universal refractory almost impossible of attainment. The relatively cheap refractories standardized in fuel-fired furnaces have been very largely used in electric furnaces. There is, however, a growing use for specialized "super-refractories," even at greatly increased cost, that will stand various especially severe conditions in certain kinds of work.

Important recent developments are higher firing temperatures, the use of high aluminous fire clays, and increased experimental work on fused refractories. The commercial production of sufficiently high firing temperatures, and the development of satisfactory bonds for special refractories are at present perplexing problems.

Introduction

One of the most important problems before the electric furnace industry is that of obtaining suitable refractories, the lack of which perhaps more than any other factor has held back a more rapid development of this industry. Naturally, the requirements for the various types of electric furnaces are different. An ideal refractory would be one of universal application, but, unfortunately, such a refractory has not yet been developed and probably never will be. The present tendency toward better heat insulation for the purpose of conserving as much energy as possible increases the demands made upon the refractory. Fire clay, silica, and magnesite are in most general use for electric furnace work, probably because they are comparatively cheap and were already in wide use in fuel-fired furnaces, and, hence, available for use in the more recent electric-furnace industry. The fact that these relatively cheap refractories are now generally used does not mean that a refractory with a higher first cost would not be accepted by the trade. On account of the high cost of repairing and replacing linings, more expensive refractories could be used if linings of longer life were produced thereby.

General Requirements

It is difficult to list the requirements of refractories for use in so broad a field as that covered by the electric furnace industry. Each furnace and each process had its individual conditions that must be met, but certain general requirements that apply in most cases may be outlined.

¹ Presented before Refractories Division, Pittsburgh meeting, February, 1923.

A high fusing temperature is important. This fusing temperature should be determined under a load greater than that under which the refractory will be used. If the refractory lining is used without insulation, and its heat conductivity is high, that portion of it farthest from the heat will be relatively cool and a greater load will be supported than is indicated by the load test. High heat conductivity is also an advantage in refractories used for the construction of externally-heated muffles and of resistor troughs in resistance furnaces. Expansion or contraction with temperature changes causes spalling if the furnace is subjected to rapid changes in temperature. Constancy of volume is, therefore, an important requisite. Excessive shrinkage may occur in some brick when heated to a temperature higher than that at which they were originally fired, causing them to drop out, or the roof to slump. Refractories containing oxides (as, for example, oxides of calcium, iron, magnesium, silicon, aluminum, etc.) will tend to form fusible compounds with the constituents of the slag, while such refractories as carbon, carbides, nitrides, etc., may at high temperatures be oxidized by some of the oxides contained in the slag. Gases and fumes rising from molten baths have the same chemical action on the refractory with which they come in contact as do similar constituents of the slag. Metals corrode linings largely by their physical abrading action, although they may actually react with the refractory material, as, for example, carbon or silicon carbide may be dissolved by molten steel. High electrical conductivity is undesirable for refractories in most cases, although this property is sometimes used to advantage by those furnaces using a conducting hearth.

Specific Requirements of Types of Furnaces

Rather than attempt to list a number of specific requirements of refractories for different furnaces and processes, examples of the various operations will be given.

Steel Melting.—In the melting or refining of steel in the electric furnace, the temperature of the metal is raised to about 1600°C , a temperature approaching very closely to the softening point of many of the refractories in general use and far above that of some. It is evident that the linings of most furnaces must be heated to a higher temperature than this. There are two general processes used in melting steel, namely, the "acid" and "basic" processes. In the acid process, the side walls and roof are constructed of an acid refractory, such as silica brick; an acid slag is used, and no refining is done. Consequently, the charge is melted rapidly and is not held in the furnace for a long period of time. As a result, overheating of the refractory, fluxing of the side walls by the slag, and corrosion of the roof by volatilized lime are not excessive. In the basic process, a basic lining, such as magnesite, and a roof of silica are ordinarily used.

A slag of high-lime content is placed over the charge, and the molten steel is held for a long period of time in order to permit the refining to take place. As a result, the lining becomes overheated and a large amount of lime is volatilized from the slag. This lime is an active flux for siliceous materials and causes early deterioration of the roof. The lime-slag used usually contains silica which, at the high temperature prevailing, attacks the refractory at the slag line. In either process the close proximity of the electric arc to the side walls will cause super-heating and destruction of the lining near that point. Magnesia is decomposed by carbon at a high temperature and is badly corroded by the arc. Iron oxide, if present in the refractory material used for the bottom, may dissolve in the hot iron and thus introduce oxygen to the metal, increasing the refining difficulties.

For economy of construction and operation, the roof should be as close to the metal as practicable. This would require a refractory of higher softening point under load. A refractory of too high heat conductivity would cause too large energy losses and one whose heat conductivity is low, or one used with insulation, would have to withstand higher temperatures under load. The refractory material for both the walls and the roof should withstand the high temperatures under load, should be inert both toward the acid and basic constituents of the slag or the fumes, and should be unaffected by molten steel. In many instances, it should withstand rapid temperature changes without excessive spalling.

The direct arc type furnace is in widest use in this country for steel melting. In this furnace, heat is transmitted to the charge by an electric arc which passes directly from the electrode to the metal and by reflection from the roof and walls which are heated by the arc. These furnaces are built in large sizes and the refractories, especially those in the roof, are under large mechanical stresses and should withstand more severe load tests than those used in some of the other types. On the other hand, the heat is not concentrated in so small a volume as in the case of the smaller furnaces and there is not the high degree of overheating by the arc. In those furnaces using a conducting hearth, refractories for the bottom should have high electrical conductivity.

The indirect arc furnace is used in steel-melting practice, and there are several different varieties of this type of furnace in use. In the indirect arc furnace an arc is struck between electrodes placed above the charge and the heat is transmitted to the metal by radiation from the arc and reflection from the walls and roof. On the whole, these furnaces are smaller than most of the direct arc furnaces, and, hence, the refractories may receive more local overheating, but, on the other hand, the load impressed is not so high, and, as a result, the refractory would withstand a higher temperature than it would in the larger furnaces.

The induction furnace has not been generally introduced to steel-melting

practice in this country, although many advantages are claimed for it and it is in wide use in Europe. A 2-ton furnace has been in successful operation in Pittsfield, Mass., and two others are said to be in operation in this country. One factor which has kept the induction furnace from developing more rapidly has been the difficulty of obtaining a suitable lining for the hearth. A satisfactory lining for basic operation has been developed for the aforementioned furnace at Pittsfield, with which 604 consecutive heats have been obtained.¹ The induction furnace is essentially a transformer whose secondary coil consists of a ring of the metal which is heated by the electric current induced from the primary winding. The induced current gives rise to circulation of the metal which should keep the temperature of the lining uniform and prevent local overheating. In the induction furnace there are no electrodes, the heat being generated in the metal. Hence, the slag is at a lower temperature than in similar operations in other types of furnaces and there should be less corrosion of the roof by ascending vapors.

The resistance furnace has not been introduced into steel-melting practice, although one instance of its use for melting steel scrap in an experimental run has been recorded.² In the operation of this furnace most of the heat is transmitted to the metal by reflection from the roof, while some comes from the troughs containing the resistor material. Undoubtedly, the refractories in this furnace used for steel melting would be subjected to excessive temperatures. If this furnace is used commercially for melting steel, it would be desirable, in order to prevent excessive losses of heat, to find a refractory for the roof that will withstand temperatures considerably greater than do those which are now in common use.

Iron Melting.—The conditions in the operation of iron-melting furnaces are similar in almost every respect to those in steel melting, except that the metal is held molten at a lower temperature (not over 1400°C), and usually less refining is done. In the duplex process, hot iron comes from the cupola and is finished in the electric furnace. Thus, the temperature changes are not great and spalling troubles are lessened. In melting cold scrap or pig iron, however, rapid temperature changes are experienced. In general, the statements made above in regard to steel melting apply here except that none of the conditions mentioned are quite so severe in the melting of iron. Intermittent operation with the subsequent cooling of the furnace subjects the lining to severe spalling action and, inasmuch as it is desirable in foundries to operate intermittently, it is highly important that the refractory be relatively free from volume changes when passing through relatively rapid temperature changes between the limits of about 1500°C and normal temperatures.

¹ H. A. Winne, *The Foundry*, Jan. 1, 1922.

² "Melting Steel in Non-ferrous Electric Furnace," *Iron Age*, 108, 472 (1921).

Non-ferrous Metal Melting.—In most non-ferrous melting practice the temperatures used are relatively low. In many cases the highest temperature to which the metal is heated is about 1100°C , the temperature of the lining in some furnaces being raised considerably higher than this. Since these furnaces are for the most part quite small, running usually from one-quarter ton to two tons in capacity, the heat is more concentrated in the crucible and the refractory lining is subjected to more severe heating than would be the case in larger furnaces. The load under which these refractories are held would be relatively small and the requirements in this direction would therefore be less. The intermittent methods of operation with the resulting temperature changes subject the refractory to spalling, although this is avoided in some furnaces by keeping a small load on during periods of rest in order to avoid the necessity of heating up before the next melt. The absence of slags removes one important requirement, but the corrosive action of some of the fumes, particularly in the case of lead, adds one in its place. The washing of the metal over the hot surface of the lining in the rocking or rotating indirect-arc furnace causes a more even distribution of heat than is found in the stationary types. The high concentration of heat at the roof of the common resistance furnaces makes particularly heavy demands upon the roof. An important problem in the non-ferrous alloy field is the development of a refractory that can be used in melting alloys of high lead content. This is of particular significance in the case of the vertical ring induction furnace. The high-frequency induction furnace makes possible the easy attainment of temperatures higher than those usually employed, and it is highly desirable that a satisfactory refractory be developed for this use.

Smelting Furnaces.—If the electric smelting furnace is designed properly, there is less failure of the lining than in furnaces used in the various melting practices referred to above. Of course, there are exceptions to this statement, because in some smelting operations, products are formed which attack almost any lining that can be used and in such cases the success of the process depends upon the development of a suitable refractory. Most smelting furnaces are of the open-top pit type, the electrodes being inserted into the charge and the heat generated by the resistance of the charge to the flow of the electric current and by small submerged arcs playing between the particles of the charge. The most important refractory trouble is due to corrosion of the lining by the chemical action of slags, metals, or vapors.

In the production of ferromanganese, a refractory is required that will withstand the action of a basic slag carrying a high percentage of lime and manganese, and, in addition, some silica and alumina. This slag attacks both basic and acid refractories. Such refractories as carbon or silicon carbide should withstand the action of the slag better than any of the

others, but they reduce manganese and iron oxides at the high temperature prevailing and are also soluble in the hot metal produced. However, both of these refractories have given satisfaction in practice. Magnesite withstands the action of the slag very well and also is not attacked by carbon at the temperatures used. It may, however, be attacked by the arc if an electrode is pushed near the wall and excessive arcing occurs. Magnesite grout rammed with pitch has given satisfaction in a number of instances. Fire clay and the acid refractories are more readily attacked by the basic constituents of the charge but have proved very satisfactory when used in thin walls cooled by air or water, which arrangement cools the charge and causes it to solidify on the lining and thereby form a new lining.

No serious refractory difficulties are experienced in the operation of ferrosilicon furnaces. The crucible of these furnaces is usually lined with rammed carbon or carbon blocks and the wall is made up of silica or fire clay brick. The charge consists of quartzite of high silica content, rich iron ore, or scrap iron, and coke or coal. The production of slag is avoided as far as possible, the attempt being made to reduce all of the constituents of the charge to metal. The fusing temperature of the charge is so high that the walls of the furnace are soon covered with a refractory layer of partly fused silica which protects the lining from further action. Carbon is a satisfactory material for the crucible lining because it is not dissolved in ferrosilicon and a sufficient excess of carbon is used in the charge to protect the lining from oxidation.

Ferrochromium, ferrovanadium, ferrotungsten, ferromolybdenum, and some of the other less common alloys ordinarily use a carbon-lined furnace either made up from rammed carbon and pitch or carbon blocks. In some cases, magnesite is used. Carbon should be satisfactory in most instances, but cannot be used in the production of low-carbon alloys, such as, for example, low-carbon ferrochrome, in which carbon is quite soluble. In such cases a lining made up of the ore being treated proves desirable as, in ferrochrome practice, chromite has proved satisfactory; or a basic lining, such as magnesite, may be used to advantage. One of the disadvantages of carbon or silicon carbide in these small alloy furnaces is that both carbon and silicon carbide conduct the electric current and unless the furnace is designed to avoid it a large portion of the current will flow through the walls and not into the charge, thereby producing a cold bottom and other irregularities in furnace operation. Such materials as carbon and silicon carbide are also good conductors of heat, and, in order to avoid too great heat losses, should be well insulated.

To solve all of the refractory problems connected with ferro-alloy smelting, a refractory should possess the following properties: Relative inertness to the action of the slags used; freedom from oxidation by iron oxide or

the other metallic oxides present; insolubility in molten ferro-alloys; low heat conductivity, low electrical conductivity, and freedom from spalling when used in furnaces operating intermittently. The principle whereby thin walls are cooled to permit the formation of a new lining consisting essentially of the charged material may be used advantageously. This practice, however, increases the heat losses and prohibits the use of a single furnace for the preparation of a variety of alloys consecutively.

The furnaces for melting alumina, magnesia, spinel, sillimanite, etc., take advantage of the principle mentioned above, namely, the cooling of the walls and the freezing of a part of the charge on them. In this case, however, a steel shell alone is used and is cooled either by air or water. A suitable lining is readily formed by the solidification of the material being melted. This practice entails a large loss of energy by the conduction of heat through the walls but is probably the best practice when it is considered that the temperatures used (from 1800°C to 2000°C) are greater than any that the present-developed refractories are able to withstand. Furthermore, it would be quite impossible to develop a lining that would not react with molten oxides at these high temperatures.

In operation of furnaces used for the production of calcium carbide a temperature above 1800°C is required. Lime and carbon are used in the charge and it is to be expected that either a carbon or a basic lining would be necessary. However, fire clay brick can be used because the fusing point of the calcium carbide is so high that some of it solidifies next to the relatively cool lining and protects it from the action of the heat and charge.

No furnaces are in operation in this country for the electric smelting of iron ores, although there are a number in Europe and two have recently been installed in Brazil. Two kinds of furnaces are used, the shaft type and the open-top or pit type. The shaft furnace consists of a crucible or hearth, and, resting upon this, a shaft. The hearth is usually lined with dead-burned magnesia rammed with pitch. It is covered with an arched roof through which electrodes extend into the crucible. The roof consists of fire brick cooled by the circulation of gases which pass through tuyeres into the hearth just under the arch, thence up through the stack and after being cooled, return to the tuyères. The roof is the weakest point in the construction. It is probable that this furnace will be replaced in future developments by the simpler pit furnace. In the pit furnace the operations are similar to those of ferromanganese smelting and the refractory requirements are alike in both cases.

Present Developments

Important recent developments have been a wider use of high aluminous fire clays and higher temperatures of firing. The addition of aluminum

oxide to fire clay in various amounts up to and even greater than the content of sillimanite ($\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$) has produced refractories that have been very satisfactory in many instances. The presence of the excess aluminum oxide increases the fusion temperature and in many cases reduces the corrosion of both slags and gases. These mixtures have given satisfactory results in the roofs of a number of different types of furnaces, especially those of short span where the pressure has not been great. Bauxite brick are giving more satisfaction now that they are being burned at higher temperatures and all of the shrinkage has been taken care of before they are put into use.

The so-called "super-refractories" are coming into wider use and more fundamental information is being obtained regarding their properties. Silicon carbide is now a rather common article and its properties are well known and have been described in the technical literature. Fused magnesia is coming to the fore but satisfactory methods of bonding it are not generally known. Moreover, it is not definitely known whether fused magnesia will be more satisfactory for general use than properly made "dead-burned" magnesia. A well-conducted comparison of these two products is needed. Fused alumina, sillimanite, spinel (MgOAl_2O_3), zircon, and many others are being experimented with and used in commercial operations to some extent. Each one has given encouraging results and, although the pure synthetic compounds have shown remarkable properties, complete knowledge of the fundamental refractory properties of these various materials, as prepared commercially, is not yet available. The commercial product will contain impurities, and it seems very important that work of a fundamental nature be done on the commercial grades of these products. In practically all of the super-refractories now under consideration, the inability to develop a suitable bond and the difficulty of firing the brick to high enough temperature have been important factors in holding back widespread application of these materials.

Progress is being made in the solution of this important problem of developing better refractories for electric furnaces, but it will proceed more rapidly as the metallurgists and ceramists coöperate more closely in working out this mutual problem.

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A RAPID METHOD FOR PREPARING A SILICATE ROCK FLUX FOR DEHYDRATION

BY GEORGE W. BURKE

ABSTRACT

When time is an important factor in the analysis of silicate rock or clay the following method of treating the flux will be found advantageous. The molten flux is poured into the bore of a steel cylinder that is resting on an iron plate. A tightly fitting plunger is inserted into the bore and rapped smartly with a hammer. The broken flux is swept into a dish where it is dissolved in acid.

When samples of clay, sand and silicate rocks containing from 50 to 75% of silica are fused with normal sodium carbonate a relatively large amount of flux is formed that is usually difficult to remove from the crucible. Some allow the melt to solidify in the bottom of the crucible and then remove by treatment with acid. Others cause the melt to solidify

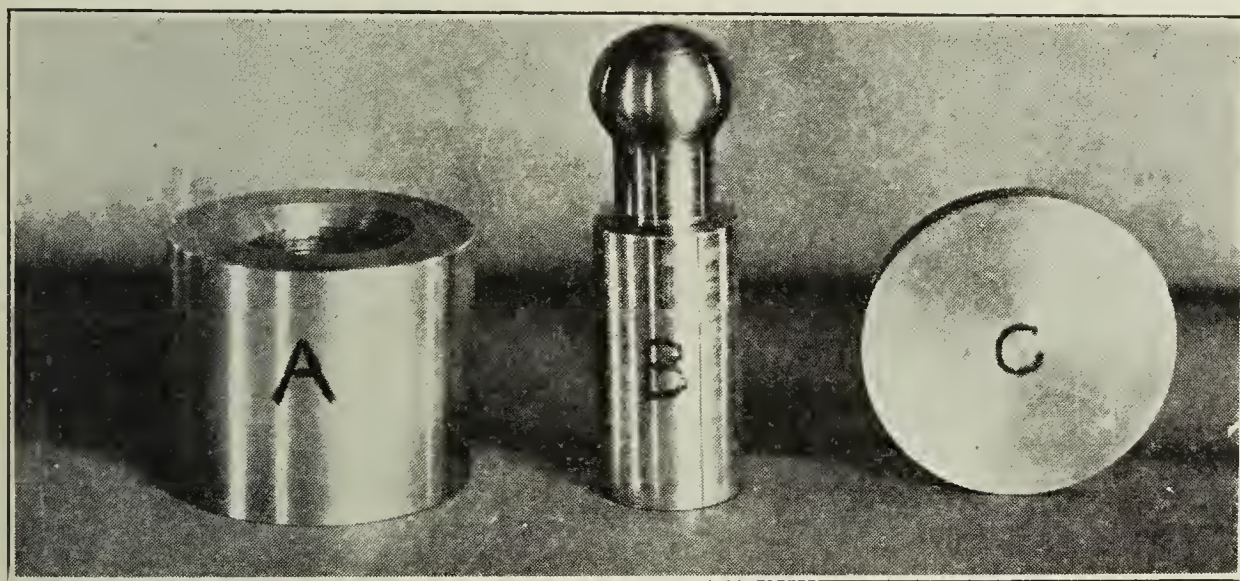


FIG. 1.—Apparatus for disintegrating the flux button.

on the sides and bottom of the crucible by giving it a gyratory motion while the flux is still hot. In this case the flux must be removed by acid treatment. Another method practiced by some is to pour the molten flux into a platinum dish that is riding on the surface of cold water contained in a beaker.

In the above cases several hours are generally required for the melt to become sufficiently disintegrated for dehydration. Again, the crucibles are held up for further use until entirely freed from the flux.

A rapid method for working up a flux high in silica is accomplished by making use of a simple apparatus. (See Fig. 1) described as follows: The apparatus consists of three pieces, a cylinder *A*, plunger *B*, and flat plate *C*, all of which are made of cold rolled steel. The cylinder is about 2 inches in diameter, $1\frac{3}{4}$ inches high and has a 1-inch bore that is bevelled at the top. The bottom is machined perfectly flat and smooth. The plunger fits the bore of the cylinder snugly and is provided with a

groove on its surface to avoid compression in the cylinder. The plate is about $\frac{1}{4}$ inch thick and is slightly larger in diameter than the cylinder. Both faces of the plate are machined perfectly smooth and flat.

For use, the bottom plate is placed in the center of a piece of glazed paper and the cylinder is placed on the plate. When the fusion is complete the crucible is seized by its rim with the tongs and the molten flux is quickly poured into the bore of the cylinder. The melt quickly cools and forms a button that does not stick to the steel. If one so desires the melt can be poured out into a platinum disk that is floating on cold water. When sufficiently cool the button can be transferred to the bore of the cylinder. After the button has cooled the plunger is placed in the bore of the cylinder the latter is held tightly in place on the plate, and the plunger is given a few smart raps with a hammer. Such treatment breaks the button into fine pieces. The disintegrated button is brushed on to the glazed paper and is then transferred to the dish in which the dehydration is to be made where it is easily dissolved by treatment with sufficient quantity of 1:1 hydrochloric acid. The thin film of flux remaining in the crucible can be quickly removed by immersing the latter into the dish containing the dissolving flux.¹

By the method described above the crucible in which the fusion was made can be liberated for further use in a very few minutes, and the flux is ready for dehydration in about one half hour.

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¹ If such an apparatus as described above is not easily available a diamond motor such as is used by mineralogists can probably be satisfactorily used.

CLAY AS A MEDIUM THROUGH WHICH EDUCATIONAL IDEALS MAY BE EFFECTIVELY PRESENTED¹

BY JAMES C. BOUDREAU

Introduction

Education is the threefold growth of man, physical, mental and cultural. Pedagogy is the science of fostering this growth. If, as an educator, one appreciates that he is not teaching art, handwork, mathematics or English, but rather is teaching children through the medium of these subjects, the objectives will be expressed and the results measured in terms of child growth.

Clay, because of its individual properties, offers many unique possibilities of presenting educational ideals that cannot as effectively be realized through any other medium. Two facts are quite evident in the program as applied to education in public schools built around clay; first, that the objectives are variable in different grades; second, that emphasis is primarily upon education in art appreciation.

Educational Possibilities

Two years ago at Columbus, on invitation from the AMERICAN CERAMIC SOCIETY that I be present in the interest of education at the formation of the Art Division, I gave a short talk presenting the educational possibilities open to such an organization. I found I was a little out of step with the rest of the group, and my presentation was not very favorably received, not because it was not worth while, I think, but because the people in the section at the time were very busy thinking of and discussing other phases of the activities of the Division. At that time the thing that was all engrossing was the possibility of trying to interest the manufacturers in the need of employing artists to increase the value and the beauty of their ware. I, striking my discord rather emphatically, brought out the point that I thought that that was not the only thing we should do in an Art Section. I maintained that we should have an organized program whereby we would develop the art appreciation of our buying public, and that only by giving the right work in our art courses in the public schools could we raise the standards of the buying public; for the children who today were in school, tomorrow would be the purchasers of our different manufactured products. The meeting two years ago was centered on the fact that ceramic artists should be employed. We gave no thought at that time to the educational value of ceramic work. Since then I find that some of those people have had a chance to stop and think, with the result that they realize that perhaps, after all, it is well for the AMERICAN CERAMIC SOCIETY to be interested in the way art appreciation is developed in the public school program.

¹ Presented before the Art Division, Pittsburgh Meeting, February, 1923.

Cultivating Art Appreciation

As you know, the average manufacturer, irrespective of the field he is in, cares little about art from the standpoint of art appreciation. That is not his business. What he wants to do is to develop a product that will sell. Now, it is our aim to have a market of tomorrow that will demand better ceramic products. Therefore, we must project an educational program of art appreciation having ceramic content.

A parallel change for the better, as the result of art education in the public schools, is evident in the difference in textile offerings of today as contrasted with those of only a few years ago. Ten or twelve years ago you could visit any worth while department store, and in the rug department be confronted with quite a preponderance of those hideous rugs with realistic dogs or roses or castles on them. We all recall them. About a month ago I was at one of our department stores, and looking around saw none of those grotesque floor coverings. Incidentally, I put this question to the head salesman, "What has become of all those picture rugs you used to sell the buying public?" to which he replied, "Well, the demand has dwindled to the point where we finally have ceased to stock them; the public will not buy them; they want something better in design." It is no mere accident that this evidence, the fact that American standards in textile desires have been raised, coincides with the national acceptance of design as a subject in the public school program.

Now, if we have a definite art educational program in relation to the ceramic field, there is no doubt but that the public, which will buy tomorrow, is going to demand better things, and naturally if they cannot get them in this country, they will get them from other countries. Our function, therefore, is to develop the appreciation of the coming buying public, and then there is not a doubt in the world but that our manufacturers will meet the demand of their public, thus calling into service our artist potters. It is their duty to have something that will sell to the public. I say, they do not care; it is not within their function to care whether it is beautiful or hideous, just as long as it sells. Of course, we of artistic bent are intensely keen that it be beautiful as well as salable. To realize our desire, our educational program and our art pottery program should go hand in hand. We have to have many appreciators where we have only one creator.

In the entire art program in the public schools in Pittsburgh, our effort is primarily to develop art appreciation. I shall not go into detail in relation to any activities other than clay. As was stated in the introduction, education means the threefold development of man, that is, the physical, mental and cultural development. We feel in our art program, as a whole, that our main emphasis should be on the cultural development, for there

we have an opportunity that no other subject, not even music or literature, can touch as effectively as we can.

Clay Modeling as a Means of Self-Expression

While that is our main emphasis in relation to studying clay in the Pittsburgh program, we find we can foster through clay other developments, certain mental and physical growths that cannot as successfully be reached by other means. You will notice, as I unfold the program of the public school, from the first grade through the high school, that there are varying objectives, and also that the objectives are stated in terms of growth of the child and not in terms of objective results. In like manner we measure our results in the attained growth, and not in the objects that are created by the child.

In the first four grades we use clay in the Pittsburgh schools chiefly as a means of self-expression. It goes hand-in-hand with writing, drawing and speech. We find that the child can talk through the language of clay with a facility that is not equalled in other mediums. A child is often handicapped in his oral expression when he tries to talk about something, but if he is allowed to express himself in clay, he can talk very effectively. The ready responsiveness of clay wins the love of the child and immediately unlocks those creative desires so precious to mankind. He can express his ideas much more clearly in a concrete than an abstract manner. So in the first four grades we use clay primarily with that objective in mind—to develop this additional facile means of self-expression. But along with it, we get a certain physical development, particularly a better control of the finer muscles of the hand and forearm. This work improves, by repeated experiences, the coördination of the hand and mind. No other medium presents an equal opportunity to develop two-handedness. While in drawing, the child's self-expression is in terms of two dimensions, in clay work, he has a chance to think and express in three dimensions. In these several objectives, we are using clay as a pedagogical asset, because of its own individual characteristics, an approach quite apt to be foreign to you and me as ceramists.

In the fifth grade, we change our objectives. Here we start to study the use of clay from the standpoint of the sculptor and of the architect. We allow the child to do a little modeling and some architectural detail, with the objective absolutely upon art appreciation. It is the first manipulative introduction the child has to a knowledge of the sculptor and the architect and their art creations. We are not trying to make sculptors or architects in this work in the fifth grade, but rather to develop an appreciation through the very valuable concrete means of a definite contact with the materials that these two great art contributors use.

In the sixth grade, we place our emphasis upon an appreciation of pottery

together with an industrial insight into ceramic production. During this year the child does a bit of building—not, as I say, to make potters, but to get an intimate appreciation of the potter and his product. We stress the beauty of line and form rather than technique. Also in this grade we do some casting.

Subjective Results Obtained

We are not working for products in the sense of the objective results, but are teaching art appreciation. It is an accepted fact that one of the most forceful ways to learn is to do. We can read about paintings, but we shall never appreciate the artist's problems as thoroughly as when we are allowed to take a brush and paints and try to do a little painting—we soon realize the painter's possibilities and limitations.

Where convenient, the children, as a community group, develop two or three molds from which every child pours at least one piece. Our objective here is an introduction to one phase of the ceramic industry. By teaching the process of casting, we acquaint the child with one of the big industrial possibilities of clay; since we all know we would not get very far in our ceramic industry if we had to build all our pottery by hand, as did the first potters, I feel the child has a right not only to know how primitives built, but also how we produce our pottery today. Through casting we have an excellent opportunity to realize our second sixth grade objective, namely, a knowledge of ceramic industrial production as related to pottery.

In this city we are gradually changing to what is known, in educational circles, as the 6-3-3 plan, six grades for the elementary school, three for the junior high school, and three for the senior high school. As soon as we get organized definitely in the junior high school, it is my hope to have clay in each grade. At present our emphasis in relation to clay in the seventh and eighth grades is the further development of the appreciation of sculpture, architecture, and pottery by means of pictures, lantern slides and exhibits. During the eighth year all the public school students visit the Department of Fine Arts, Carnegie Museum, three times as part of their regular program. Three lectures, one on each of the fine arts painting, sculpture and architecture, are given using the very excellent material at the Museum for illustrations.

The program at present, then, provides that every child in the Pittsburgh schools has an actual contact with clay in each of his first six years in school. As soon as the junior high school plan is in complete operation, every child in the seventh and eighth grades will enrich his art appreciation through manipulating clay. From the end of the eighth grade on, as at present the art work will be elective, starting with the ninth grade or with what at present constitutes the regular four year senior high school.

High School Program of Study

It is well to acquaint you with our objectives in Pittsburgh relative to that part of our high school art program that involves the use of clay. Perhaps the best way to present them will be to first state our negative objective. We are not teaching pottery in the high schools of Pittsburgh with the idea of giving all a vocational training. It is not primarily a vocational course. We do not claim, when a student leaves the senior high school, that he is capable of taking a position as a tradesman in any pottery plant, any more than we maintain that he can go forth as a trained art potter ready to open up a studio of his own for creative work. Instead, we carry very much the same thought through the high school program that we have in the grades, namely, a cultural growth through the development of art appreciation. This major objective, however, is supplemented with another which has vocational significance. We watch for the students of special interests and aptitudes. They are given specific information regarding the opportunities of the ceramic field. As a result we send to craft and ceramic schools some of our high school graduates each year.

We are able to present a very rich experience in the high school because of the fact that the students who take the pottery course spend much time with us during a school year. When one elects pottery, he has one credit hour period every day in the school week, so that in a year's time he has taken pottery for forty weeks, or two hundred credit hours. While our course is scheduled as pottery, each student does some modeling also.

The following is the program by which we claim and feel confident that our objectives are realized. We have a general approach for all our students and a specific approach. In the general approach every student who elects the pottery course has some contact with art appreciation as revealed in painting, sculpture, and architecture. This phase of the program includes at least six sessions during the year devoted to the Fine Arts and may be developed by any of the following means: lectures, reports, loan exhibits, discussions, museum trips or other excursions. In our specific art appreciation program, we emphasize the crafts. Every one studying pottery in the high school has an opportunity to become acquainted with the several art crafts, including bookbinding, jewelry, metal work, such as copper and brass, iron work, block printing, and textile dyeing. This craft appreciation is realized by the several above-named means of development.

Naturally our very definite craft appreciation in the pottery department is centered about pottery and modeling, and we get our concrete approach through the one medium of clay. One may elect metal work, bookbinding or block printing instead of pottery as their craft subject,

yet the course is fundamentally the same; the craft appreciation is the same, but they have a chance in the studio or laboratory to apply it to some other specific medium. We could not possibly have a child work in all the various crafts in a year's time. All are given the general approach to the several crafts and then they apply this general information to any one craft they may have elected.

We also have a color and design approach, both from the standpoint of theory and application. In our theory we study the principles of color and of design. In our application we note the evidence of these principles in the various crafts and then apply them specifically to the pottery. We present an enriched insight into chemistry as the result of our glazing and firing activities. From raw materials are compiled our entire glaze palette, and there are always a few test pieces in every fire. The interest of the students in this part of the program, as with us, is very keen.

We have in operation a policy in connection with our high school pottery program, relative to pupil eligibility. We aim to reach as many people in the high school as possible. This policy naturally develops as a result of our objectives. After all, the public school is not an art school. It is a general educational institution, and I believe firmly that the main function of art education in the high schools, as in the grades, is to develop that phase of educational growth, which cannot be reached successfully by other subjects. Therefore, in putting our emphasis on culture, we should try to reach as many students as possible in high school.

We much prefer to have two hundred students take pottery for a year than to enroll one hundred for two years. We have a few students with us beyond the first two semesters, but we only permit these few to come in for advance work when space remains after satisfying new students' requests for admission.

Instituting any school with a major vocational intent must employ an opposite policy. It may be that some time in the future, local industrial development will justify the instituting of vocational courses in pottery in addition to our present program. If it does, we shall develop a new program of different objectives and policies to meet the new need.

From the outline of our high school program, you can see that we do not employ the entire time of our students in execution, but rather we present the handling of clay as an enriching supplementary and laboratory experimental approach for the purpose of concretely reinforcing the "Art Appreciation" objective. Our thought is to develop an attitude rather than many pieces.

I have stated in detail both the grade and the high school program to show you that our objectives are different from those of either the manufacturer or the creative potter. Yet despite these different approaches to clay that the educator, the manufacturer and the art potter have,

nevertheless, we all have many things in common. We are all going in the same direction, but through different avenues, and I am confident that if we are to arrive, we must know and understand each other thoroughly. Let us all so coördinate in the future that we shall realize to their fullest measure the educational ideals that may be effectively presented through clay as a medium.

Discussion

C. F. BINNS:—I have never heard a better presentation of the ideals and work of a grade and a high school art program than Mr. Boudreau has given, and it appeals to me very strongly indeed. I congratulate him upon it. I would like to see this address distributed far and wide, if it can be done. The schools need it, and if these ideas can be carried out we shall have accomplished a good deal.

CHAIRMAN F. H. RHEAD:—I should like to second Professor Binns' remarks in connection with that paper. Do you know how many years ago it was when we had our first Art Division meeting?

J. C. BOUDREAU:—That was two years ago, in Columbus.

CHAIRMAN RHEAD:—The first Art Division meeting was very cut and dried. We had worked some time on it. Mr. Solon had a paper; Mr. Dressler had a paper on faience; and there were one or two other papers. We read these papers and transacted our business; then this young man stood up and talked along these lines. I am interested in the industrial side. I have gone through the curriculum of the English Art Student but I had never realized his point of view at all. After the meeting was over we discussed these new ideas that were being thrust upon us. We couldn't understand them at all. The idea that anybody should have an education in art appreciation, should be taught something that he was not going to use in later life in a practical way was new to us. The wisdom of teaching art to someone who would not use it seemed dubious. Now we are so enthusiastic about this phase of the possible work of the Art Division that we have divided the activities of the Art Division into the educational side and the industrial work, and Mr. Boudreau is going to direct that educational side of the work.

G. O. TOTTEN, JR.:—I am very much impressed with Mr. Boudreau's paper. I do not know the status of the schools in Washington, D. C., where I live. I have just suggested to Mrs. Totten, who is a sculptor, that we make a survey of the situation in the public schools at Washington.

H. S. KIRK:—I am extremely interested with the educational possibilities of spreading this plan, because I know from the manufacturers' standpoint that they are out to supply the public with what they demand. If you are going to raise your standard product, you will first have to raise the standard of your buying public.

IMPORTANT COMMUNICATION ON THE RAILWAY SITUATION

Due to the war and the long continued impossibility on the part of the railways to finance the necessary betterments, both our production capacity and consuming demands have now advanced beyond our transportation facilities. The railway managers under the recent improved conditions are making great effort in finance and expansion of facilities to meet our necessities, but full recovery of lost ground must be slow and, if we are to maintain our present rate of productivity and employment, it is vital that there be coöperation with the railway management from both producing and consuming industries to secure the most efficient operation of the railroads.

The railways have asked for this coöperation, and the trades can make a tremendous contribution to the orderly march of our prosperity if they will undertake it seriously and in an organized fashion.

The principal directions in which such coöperation can be extended by the trades are:

1. The advance storage of their winter coal during the light consuming season—that is, from now until September 1, including the early movement of Lake traffic.
2. The loading of all cars to full capacity, their prompt loading and discharge.
3. Reduction of reconsignment shipment and restriction of to-order bills of lading.
4. Demands for no more cars from the railways than can be promptly used.

If we could secure the maximum efficiency in these directions we will have added more effective commodity movement than would be brought about by the addition of approximately 300,000 cars and 3,000 locomotives and the addition of at least 10 per cent to our track mileage and terminal facilities.

The importance of this lies in more than simply the maintenance of continuity of production and full supply of consumption, because any strangulation in movement of commodities through car shortages affects the profits of every individual manufacturer by interruption in his production and furthermore, such strangulation affects price levels in the most definite fashion.

The full and smooth movement of all of the productivity of the country would be the greatest contribution that could be made at the present time in checking inflation or increase in price levels.

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ORIGINAL PAPERS

THE RELATIVE MAGNITUDE OF RADIATION AND CONVECTION HEATING IN A MUFFLE KILN¹

By J. T. LITTLETON, JR.

ABSTRACT

Rates of Heating by Convection and by Radiation in a Muffle Kiln, 38" x 18" x 36" high, were each determined for temperatures from 350° to 800°C from measurements with a steady flow water calorimeter whose surface was first gold plated and then covered with a mixture of platinum black and lamp black. Taking the reflecting powers as 91 and 4 per cent, respectively, for the two surfaces, the radiation heating increases approximately according to the Stefan-Boltzmann fourth power law, while the convection heating comes out proportional to the temperature difference between calorimeter and muffle; that is, $C = \gamma(T-t)$ where $\gamma = 2.34 \times 10^{-4}$ gm. cal./cm.² sec. The ratio of convection to radiation decreases from about .40 at 350° to .10 at 800°C, so that for the higher temperatures the convection heating may be neglected in rough computations of the rate of heating in such a kiln.

Introduction

The rate of radiation absorption by a body of known temperature in an enclosed space having walls at a known constant temperature can be easily computed by the Stefan-Boltzmann formula but this heating rate is only a part of the whole. The heat received from the surrounding gases which is called convection heating will evidently depend upon the freedom of circulation of gas about the body considered and since it has not been thoroughly studied has not been subject to computation. Due

¹ Presented before the Glass Division, Pittsburgh Meeting, February, 1923.

to the lack of knowledge of this factor, very little attempt has been made to compute heating rates.

Cooling by convection and radiation has been studied by Langmuir on surfaces disposed in a certain definite way. His observations show that radiation cooling is very much greater than convection cooling. However there seems to be a somewhat general belief, among operating engineers at any rate, that radiation heating may be neglected in comparison with convection heating. The results of this paper on heating confirm Langmuir's conclusions on cooling and indicate that in all cases except where flames are playing directly upon the body radiation heating is much the more important factor of the two and for very high temperatures convection heating can be neglected with probably no more than a 10% error.

Theory

The Stefan-Boltzmann law is

$$1 \quad J = \sigma(T^4 - t^4)$$

where J is the total energy absorbed per cm.² per sec. by a black body at absolute temperature t^0 from another black body at absolute temperature T^0 and σ is 1.277×10^{-12} gram calories. If the body at temperature t is not a black body but has a reflecting surface, J will be decreased by the amount of the reflection. If the reflection be .90, J will have a value only one-tenth of that of the black body surface.

The convection heating may be assumed to be proportional to the difference of temperature between the body and the gas. This may be written as

$$2 \quad C = \gamma(T - t)$$

where C is the total convected energy per cm.² received by a body at absolute temperature T from a surrounding gas at temperature t , and γ is the constant applicable to the particular configuration. C does not depend upon the optical condition of the surface but is the same for a reflecting surface as for a black surface if they are otherwise identical.

Let Q be the total quantity of heat per cm.² per sec. received by the body, then

$$3 \quad Q = RJ + C$$

where R is the reflecting power of the surface. Since C does not depend upon the optical condition of the surface it may be eliminated by simultaneous solution of the two equations for the body having two known reflectivities as

$$4 \quad Q_1 = R_1J + C$$

$$5 \quad Q_2 = R_2J + C$$

$$6 \quad Q_1 - Q_2 = J(R_1 - R_2)$$

¹ *Trans. Am. Electro-Chem. Soc.*, **22**, 299 (1913).

Hence J is determined in this case by measuring Q_1 and Q_2 or by measuring the comparative rates of heating of the same body under the same identical conditions except for the reflecting power. C may then be immediately obtained, and substitution of this value in equation 2 gives γ , and if γ is known, the total quantity of heat Q , in equation 3, may be computed for any desired temperature and temperature difference.

Experimental Method

The heating chamber investigated was a Drakenfeld muffle kiln approximately 38 inches long, 18 inches wide and 36 inches high. Accordingly this work only applies to muffle heating.

Since it is necessary to make measurements on a body with its surface having two different reflecting powers, it is evident that the greater the difference in these two reflecting powers the more accurate will be the measurements. Accordingly a surface covered with a mixture of platinum black and lamp black having a reflecting power, according to Coblentz, of 2% was compared to the same surface cleaned and gold plated. The reflecting power of the gold surface was assumed to be 91%. This value

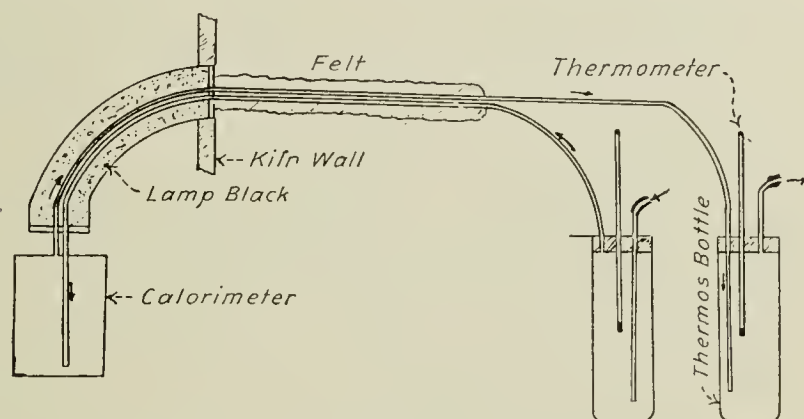


FIG. 1.

is of the same order of magnitude as the value given in the tables but the basis for assuming just 91% as the reflecting power constant will be given later. Since the blackened surface showed a few scattered pits and means the reflecting power of 4% instead of 2% as given by Coblentz was assumed as being probably more nearly correct.

A copper calorimeter approximately 10.6 cm. high, 9 cm. in diameter, 27.4 cm. in area and 0.75 mm. thick was used as the body for which the rate of heating was to be determined. The apparatus shown in Fig. 1 illustrates a simple calorimetric scheme for measuring this rate. Water from a tap was run through a one quart thermos bottle in which a thermometer graduated to one hundredth of a degree centigrade was immersed. The water flowed from a thermos bottle through a $1/4$ -inch brass tube into the calorimeter and out into a second thermos bottle. The rate of flow of the water was adjusted so that the temperature of the calorimeter did not rise more than 15°C in the maximum case. The rate of flow of the water was measured by a stop watch and a 1000-cc. graduated flask. Hence the total quantity of heat Q in gram calories absorbed by the calorimeter is the flow of water per second through the calorimeter times the change in temperature of the water measured in centigrade degrees.

The furnace temperature was determined by means of six iron-constantan thermocouples placed one couple at the center of each wall. An average of the six thermocouple readings was taken as the average wall temperature. There is undoubtedly some difference between the thermocouple readings and the wall temperature in a case of this kind but for the purpose of this experiment this method was considered as sufficiently exact. The temperature readings of the different couples with the exception of the one in the front wall which was lower than the others by about 10%, did not vary among themselves more than 10°C. The furnace was allowed to attain a constant temperature before a calorimetric measurement was made.

To determine the correction for the heat gained through the connecting tube, a blank run was made with a brass tube entirely insulated like the tube shown in Fig. 1, but instead of leading to the calorimeter the tube used had a U-bend in the bottom, this being also insulated. The rate of heating for this tube was determined for different temperatures in the furnace up to 800°C. The curve thus obtained between this rate of heating and the temperature of the kiln was used as a correction in the other experiments so as to eliminate all heating except that of the calorimeter. The blackened calorimeter was then put in place and the rate of heat absorption at different temperatures determined.

The temperature of the external surface of the calorimeter was assumed to be that of the outgoing water since the total quantity of heat absorbed by the calorimeter was not sufficient to introduce a temperature gradient through the calorimeter wall of anything like 1°C. The actual temperature varied from 15°C to 30°C depending upon the rate of heat absorption. Computation proves that when T is large, errors in measurement of t are relatively unimportant as regards radiation heating.

The procedure was slightly different in the case of the gold plated calorimeter. In this case there was a noticeable tendency for water vapor to condense on the calorimeter giving a film of water as a reflecting surface instead of the gold. Since water has a fairly high absorption coefficient for the existing radiations the results under these conditions were unreliable. Accordingly the furnace was heated above the maximum temperature desired with all the apparatus in place, and then the door was opened and the calorimeter quickly dried off and polished. The observations accordingly were taken with the kiln cooling instead of at a constant temperature. However the rate of cooling was so slow that the temperature did not change more than 1°C during a measurement. Under identical conditions a test made on the black calorimeter showed the same rate of heating with the flames off as with the flames burning proving that the presence of flames in the muffle did not affect convection inside the kiln.

In this manner the total quantities of heat absorbed by the calorimeter under identical conditions except for having two largely different reflecting surfaces were obtained. These results are shown in the curves in Fig. 2.

The values of J at any desired temperature follow immediately by a substitution in equation 6 of the values of Q_1 and Q_2 obtained from the curves. Having thus deter-

mined J , C follows at once from equations 4 or 5. By a cut and try method it was determined that the assumed value of 91% of the reflection coefficient of the gold plated surface gave a straight line for the curve between the temperature and convection heating.

The radiation heating and convection heating curves as obtained in this manner are plotted in Fig. 3. The radiation curve computed for the Stefan-Boltz-

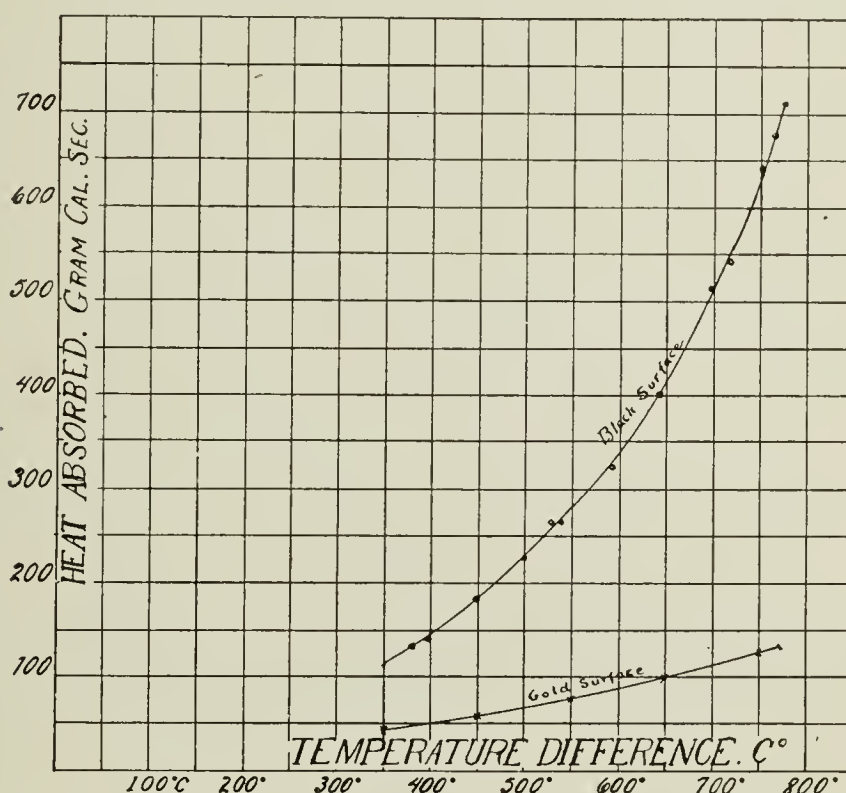


FIG. 2.

mann formula is plotted for purposes of comparison. While this curve does not coincide exactly with the curve as measured, the difference between the two can be accounted for if the thermocouples do not give the actual wall temperatures. Furthermore the colder wall of the kiln subtended a greater angular section of the calorimeter as it was nearer this wall and the wall heated directly on one side and not the bottom. The fact that the average temperature was taken instead of the 4th root of the mean of the 4th power temperatures introduces a slight error. The convection heating curve passes through the origin of the coördinates as it should according to the assumed equation.

Since the area of this calorimeter was 427.4 cm.² the value of γ or the convection constant is obtained by dividing the slope of the curve by the area of the calorimeter and it comes out for this case 2.34×10^{-4} gram cal. per sec. per cm.²

It is evident from the radiation curve that the rate of heating does not depend so largely upon the value of the temperature of the cold surface or the temperature difference between the cold surface and the hot body as it does upon the absolute value of the temperature of the hot body.

At the maximum temperature of 775°C difference obtained it is evident that the radiation is about nine times as great as the convection heating. For a case where T is 1327°C or 1600°Å and t is 0°C or 273°Å, radia-

tion heating is 27 times convection heating. It is for this reason that for practical purposes where the temperatures are high the error would not be very large if convection heating were entirely neglected. However, if a higher degree of accuracy were desired a substitution of the above

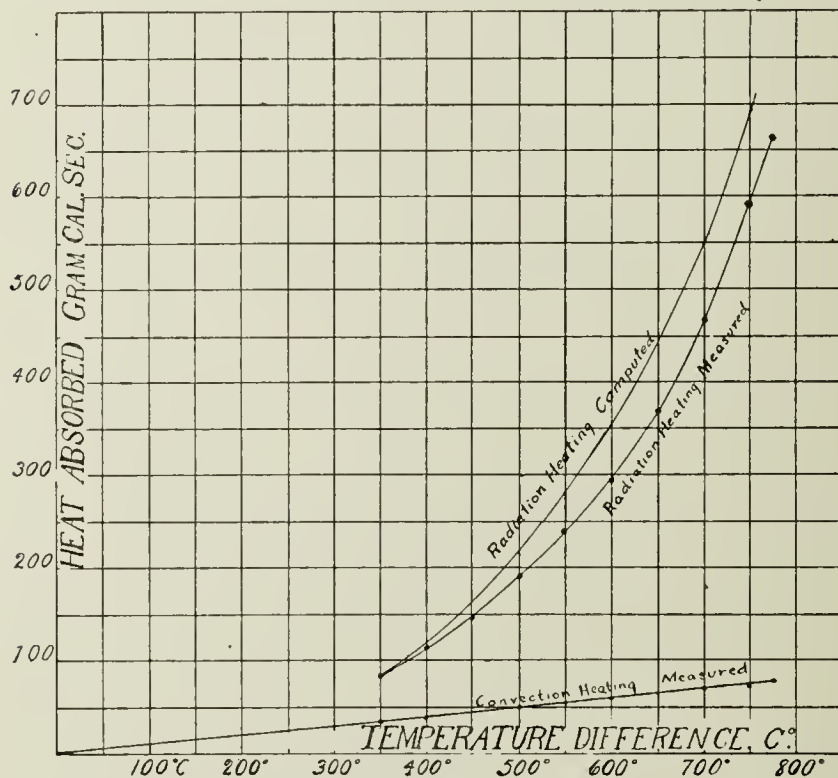


FIG. 3.

these constants, that is the radiation and convection constant, and the proper application of the ordinary equations of thermal conductivity, the heating curves and the temperature gradients existing during heating may be computed.

Summary

1. The absolute amounts of radiation and convection heating occurring in a muffle kiln of a certain type have been determined for temperature from 350° to 800°C.

2. The convection heating is expressed in the form of $C = \gamma(T - t)$. The convection constant γ is found to be 2.34×10^{-4} gram cal. per sec. per cm.²

3. The radiation heating as measured checked with reasonable accuracy that computed by the Stefan-Boltzmann formula.

4. It has been proved that for high temperatures the radiation heating is so much greater than the convection heating that unless a high degree of accuracy is desired the convection heating may be neglected.

value of γ in equation would give an approximate correction term to take care of the convection heating even though this value of γ would not apply exactly to the configuration used.

The proper consideration of the relative values of these two types of heating should be of considerable assistance in designing kilns, leers, and some types of furnaces and in the disposition of the war within them so as to obtain the most uniform and efficient heating. By means of

SIMPLE METHOD OF MEASURING COLOR

BY A. E. O. MUNSELL

ABSTRACT

Clear thinking on color is important. The Munsell System clarifies; shows color in three dimensions: hue, value, chroma. The method of measuring color on solid, sphere, irregular solid, vertical and horizontal slices through the solid. Method of notation. Summary.

It may be taken for granted that the faculty of clear thinking in the realm of color and the ability to analyze and apply color in the industrial world are of utmost importance.

The vital questions for anyone working in color are these: How shall color be freed from a fog of words and placed in a clear light? How may we define our color images, produce our color harmonies, record our results, and write all these in a complete and measured system?

In general, colors lack definiteness. Like ghosts they drift in and out of our consciousness and are effaced by the next new impression unless we form a mental habit of correlating colors by some fixed method.

The Munsell System offers such a method. To the uninitiated it may seem complicated, but in reality it is a simple method applied to clear thinking in the realm of color. This clear thinking becomes perfectly possible when we recognize the fact that each particular color has three dimensions of hue, value and chroma.

Let us consider each of these dimensions separately.

What Is Hue?—It is that quality which distinguishes a red from a yellow, or a green from a blue or red-purple. We look at a daffodil and say, "Why, yes! That is yellow. Yellow is the hue." We say that the hue of the ocean is blue and the hue of the wagon is red. The ribbons on the baby's bonnet are blue, but they are not at all the color of the deep sea blue. A brick may be red, but not at all like the vermilion of the fire wagon. So we must seek some other qualities to define more completely the color we have in mind.

What Is Value?—The blue on the bonnet was light, while that of the ocean was very dark. There we have another measurable quality of color. Is it light or dark? How light or how dark is it? *This is its value.* A maroon is a dark red (low in value), and pink is light red (high in value), yet they both belong to the same family of red.

What Is Chroma?—The red of the maroon coat, or the brick, or the pink ribbon is not at all like the strong red we see in the fire wagon. There, then, is another distinction. The weather-worn brick is very gray compared to the strong red. There is a quality by which we distinguish such a strong color from a weak one. *This is called chroma.* To say a poster is strong in color gives no idea as to its values or hues, but merely its chroma. A circus poster has strong color: a strong red, a strong yellow, and strong

blue. A catalog cover for fine stationery might have red, yellow and blue, but the chroma would be weak in order to give it a more reserved and refined appearance.

But how are all these measured? Very easily and very definitely.

Let us think of color in the form of a solid sphere like the world shown on the geography globe. Imagine that this sphere has an axis running from

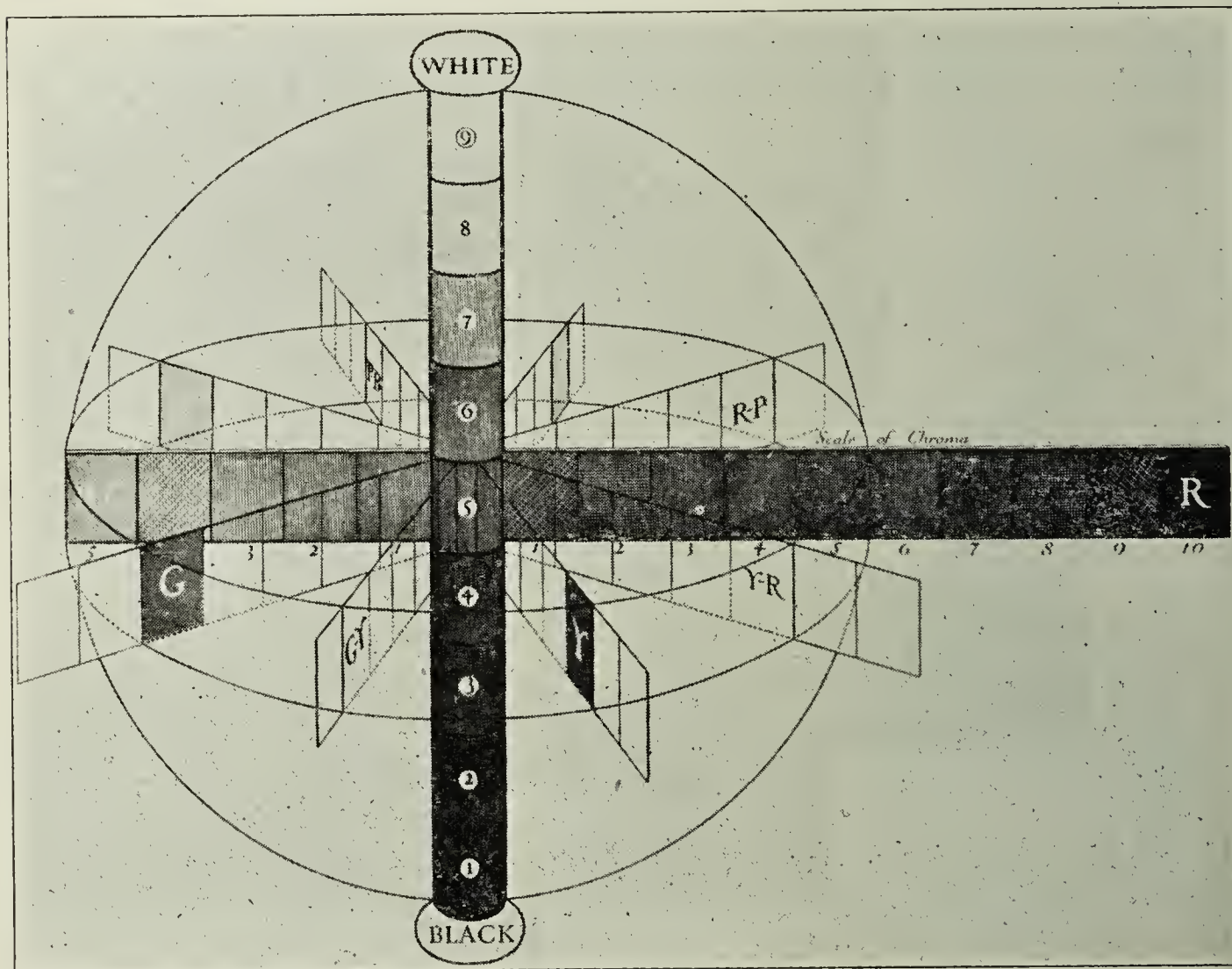


FIG. 1.—Visualizing the three dimensions in graphic form. The dimension of hue is expressed by a word or the initial letters of the word—green, yellow-red, etc., or G, Y-R. The dimension of *value* is expressed by the number of the step upon the Value scale written over a line thus—5/. The dimension of *chroma* is expressed by the number of the step on the Chroma scale, written below the line thus—/5. For example, the color at the extreme right of the diagram is Red, Value 5, Chroma 10, and is expressed as R 5/10.

the north to the south pole. The bottom of the globe, or the south pole, is black, and the top, or north pole, is white. The axis within is graded from black to white through a number of equal steps. Let us think of it as ten steps from black, 0, to white, 10. Half way up the axis we find a gray, 5, midway between white and black. Above are lighter grays, and below darker grays. But these are merely grays, with no hint of any hue—simply gradations between black and white. This is our *value scale*, and

by it we may measure any value and be able to tell whether the blue ribbon is nearer white, and the deep blue sea nearer black, or just where in the scale each belongs.

Around the globe imagine a band drawn at the equator. If this band is divided into five equal sections around the globe and each section painted with red, yellow, green, blue and purple, respectively, we have what may be called the hue circuit of five principal hues. We may divide the circuit into ten hues, the principal and intermediate colors: red, yellow-red, yellow, green-yellow, green, blue-green, blue, purple-blue, purple, and red-purple, back to red.

We often find colors which do not exactly correspond to one of these ten principal hues but which lie somewhere between two of them. For the purpose of more accurately placing these colors we may further subdivide each of the ten hues into ten smaller portions, thus creating one hundred divisions in our hue circuit.

As this particular circuit lies on the equator we know it is half way between the black of the south pole and the white of the north pole. Therefore these colors are all of middle value, $5/$, none lighter and none darker than any of the others in the circuit.

Where, then, are the lighter and darker colors placed? They are placed above the equator if they are lighter, and below if they are darker. Imagine a series of bands about the globe above and below the equator like the zones of the earth. Above, toward the north pole are the rings, or zones, of lighter colors: the light reds, light yellows, light blues, etc. Below the equator are bands of darker colors: dark reds, dark yellows, dark blues, etc.

Our maroon, then, belongs on a circuit below middle value, and in that part of the circuit devoted to red; daffodil yellow belongs above the equator, nearer white, in the yellow part of the circle.

Perhaps a red is at middle value, that is, half way between black and white. It may also be a definite red so that we are able to place it in its proper place in the hue circuit. But how shall we distinguish it from that fire wagon red which is also of middle value and definitely red?

We are imagining the sphere as solid in color. The central shaft is a series of grays—neutrals. If we start at the place on the equator where we have placed the red of our brick color and draw an imaginary line inward to the middle value gray, we will see this line passing through regular gradations of color from the easily discernible red of the brick to the neutral gray with no hint of red. The line passes through colors, all of which are reds, but each step inward grows grayer and weaker than the last. If, however, we follow the line in the other direction, away from gray, but traveling beyond the equator of the globe out into space we pass through steps of red, each stronger than the last, until we come to the red of our fire wagon. This is a strong, fully saturated color.

Between the strong red and neutral gray we may distinguish ten equal divisions, or steps of strength, which we term *chroma*. The red of the fire wagon is of the tenth chroma or ten steps out from neutral gray. The red of the brick which appears much grayer is only half as strong in chroma, or five steps out from neutral gray. The daffodil yellow would go out about as far as the red, but as it is much lighter we would find it on a higher level of value. The blue of the ocean is grayer than the strong red and also darker, or on a lower value level.

Now instead of considering the spherical globe alone as solid, so that we go out into space to reach these stronger colors, let us imagine the whole world of color as a somewhat irregular solid, with the strong color portions

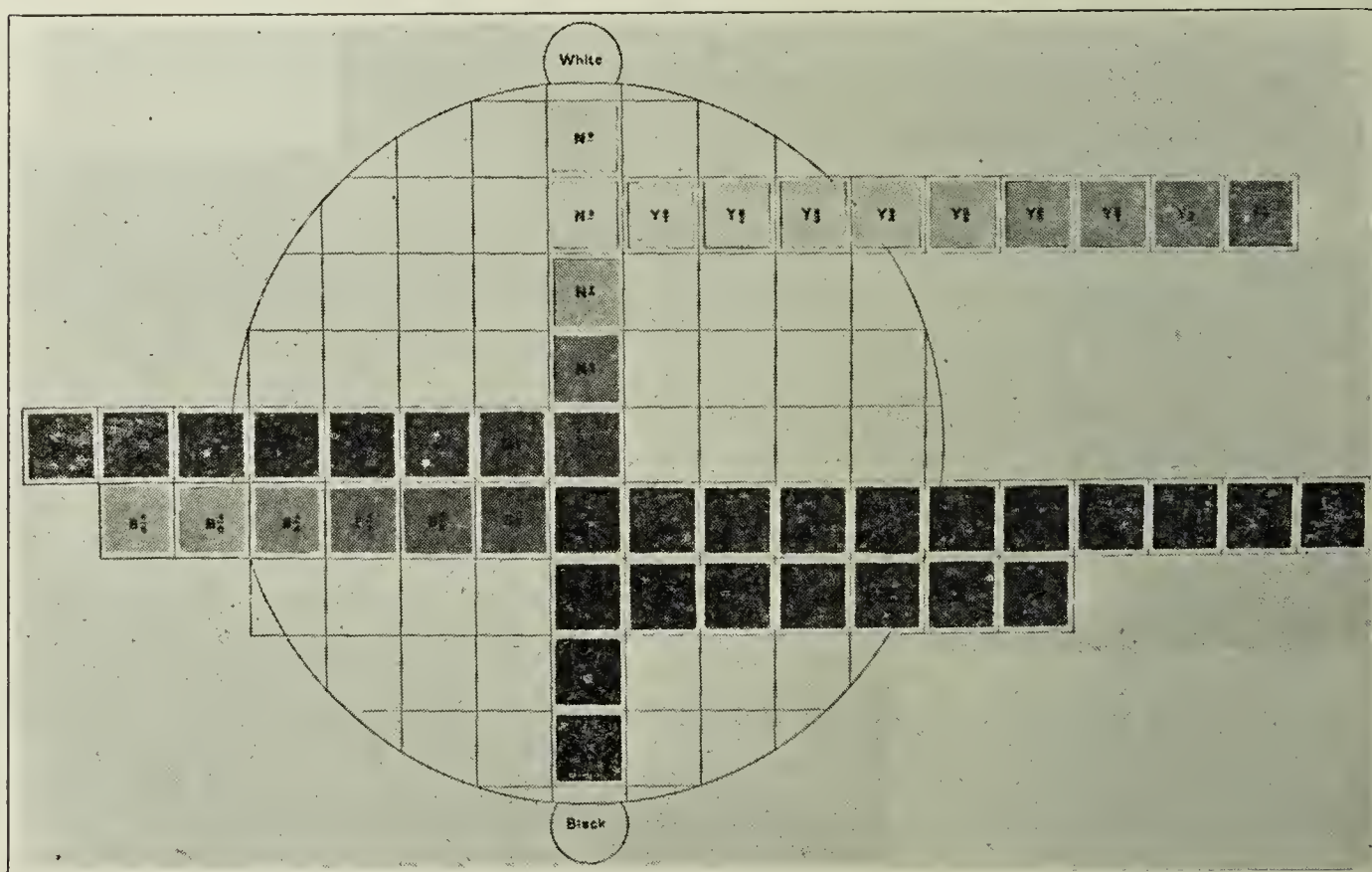


FIG. 2.—Chart C of the Munsell Atlas Chromatic Branches of the "Color Tree."

as mountains on a spherical world of color. Then the strongest red would be on a mountain peak ten units of measurement away from central gray, and the blue would be on the surface of the globe only five units out from gray, and nearer the south pole because it is darker. The yellow mountain would be nearer the north pole because it is lighter.

If we could cut vertical slices through this solid we would have exposed to view a vertical plane for each hue and its opposite. Thus, if we cut through red from north to south, or top to bottom, we would also cut through blue-green which comes opposite red on the hue circuit and there would appear before us a plane with black at the bottom, white at the top, reds on one half and blue-greens on the other half, a scale of neutral gray

in the middle with the chromas extending out from the neutrals, red to one side, and blue-green to the other. The reds would grade from dark reds at the bottom to light reds at the top of the chart, and from weak reds near the neutral scale out to strong reds. The blue-greens would do likewise. This is what we see on the charts of the Munsell Color Atlas. By cutting slices in this way we might form vertical planes in any of the 100 hues.

Or we may form horizontal planes by slicing our color solid from left to right parallel to the equator. If we cut through the equator we have a plane of color with radiating lines from gray in the center to all the hues about the circuit. All of these colors will be half way between black and white in value, none lighter and none darker, and they will vary in chroma from neutral gray in the center to the strong reds, greens and blues away from the center.

The lighter colors will all be found in the planes parallel with the equator but with higher levels of value, nearer to the north pole. The darker colors will all be in planes cut at lower levels, or nearer the south pole.

With this form in mind, how are we to write some sort of formula for the colors, say the two reds, in a simple and clear manner?

We measure hue around the circuit, dividing the whole into 10 principal hues indicated by their initials R, YR, Y, GY, G, BG, B, PB, P, RP. The red of our brick and fire wagon were the same red, having no yellow and no purple in them. Therefore they were pure red in hue, and this is indicated by the initial R (R = Red).

We divided our neutral value scale into ten steps. We find that the value of both these reds is 5, or half way between black and white. After the R we write the number 5 *above* a line, thus: R 5/. If it were a light yellow it might have been written Y 8/, indicating that the yellow was of the eighth level of value, or very light.

We divide our chroma scale, or radii of the circular plane into ten steps. The fire wagon red is at one extreme of the red radius. It is ten steps out from neutral gray. We write that figure after the hue, *below* a line, thus: R /10. Combining these figures in a formula we write R 5/10. For the brick color which is only five steps in chroma we write R 5/5.

This, then, is the formula whereby any color can be placed as closely as a pin point on the color solid: H V/C. H equals Hue, V equals Value, and C equals Chroma.

The hue is red.....	R
It is the fifth step of value.....	R 5/
It is the tenth step of chroma.....	R 5/10

We might have a light red vase with a slightly yellowish cast. It might be the ninth step in red (getting nearer YR) or 9R; it might be light in value (nearer white) perhaps at the seventh step of value—9R 7/; it might be weak in chroma, very near gray, perhaps the third chroma step—9R 7/3.

There we have it on paper. We could scribble this 9R 7/3 on a scrap of paper, tell our color man to produce a glaze of that color, and, provided he had the proper standards, he could do it.

This is a brief description of the idea of a clear thinking crystallization of color in measurable form. This scarcely begins to touch upon the possibilities of putting such a system into practice. But if one can grasp the idea of a world of color, every point of which is definitely placed and measurable, then in place of a vague and abstract idea, color has become for him a thing of positive utility.

NOTE: Further information as to more accurate hue nomenclature will be found in the Appendix of Mr. T. M. Cleland's pamphlet, "A Practical Description of the Munsell Color System."

Actual visualization of the various planes cut through the color solid with all the colors placed upon them in relation to hue, value and chroma is demonstrated in the Munsell Color Atlas.

SHOP NOTES—PLASTER SHOP

BY T. A. KLINEFELTER AND F. C. PARSONS

ABSTRACT

This paper deals with the small problems which arise in the plaster shop, and are a source of annoyance and cost if handled incorrectly. The grade of plasters used, manner of handling, method of payment, extent of reinforcement of molds, care of benches, correct procedure in making the various parts and types of molds, are all touched on.

There are a considerable number of problems in connection with the plaster shop which are of vital interest to the terra cotta man. We say "vital interest" since in a way the whole shop itself is a necessary evil—being an indirect producer of high cost, and responsible for a large waste product.

The raw material handled by the shop is plaster of Paris. This material is variable in quality depending upon the purity of the crude rock to start with, and the degree and evenness of the burn in the making.

The color is a factor of small importance of itself. The burn is of great importance, however. A fast setting plaster may cause a good deal of trouble on large bulky pieces which are thrown up, by one layer setting too rapidly for good welding with the layer next to it. This is true on medium sized molds also where they are being built by piece workers. Also a very slow setting plaster is bad on account of undue time lost.

In going from shop to shop it will be noticed that some shops work on cheap plasters and some on high grade plasters. In general ware, sanitary or electrical porcelain, we use the finest plaster obtainable to get the maximum service out of a mold. Is it necessary to do this in terra cotta, however? It seems to us that the answer is both "yes" and "no." It depends upon the number of molds expected out of a case, or the number of pieces from a mold. Then too there is the extra expense of labor and space needed if a shop should try to work two plasters together. The saving in such a case might be more apparent than real.

This leads to the question of piece work versus day work. Although it is hard to develop a piece work system covering such varied shapes, it can be done.

But the point is, does it really pay? The answer must be qualified. It depends upon several factors. In the case of models where mistakes are very costly it is not likely that it is worth taking a chance on, unless the work handled were of a rather plain, uniform character. Molds, however, are different. Here the chance of error is reduced considerably. It is rather the quality of mold turned out that must be watched.

A piece worker will not work with casting in the ordinary run of molds, but will throw up as many as he can possibly handle at one time. This results in the first layers thrown starting to harden up too much before the next round comes with resultant mold breakage unless pretty rigid

supervision is exercised. Also, there is constant tendency to shallow chamfers, no joggle holes, and all sorts of free hand work with the emphasis on the *free* very largely.

However, what is the use of going to the other extreme and carefully pouring or casting a fine mold with all the care which a day worker can exercise, when that mold will likely turn out a few pieces only, perhaps a single piece even? As long as the mold will produce a good straight piece the once or twice necessary, it will answer just as well as if it had been made of such quality as to press 1000 pieces. There are, of course, some molds where it is foolish to insist upon a cheaply turned out proposition, but in the bulk of cases, the time and money saved are well worth realizing on, to say nothing of the better service rendered the customer by pushing his work through more rapidly.

In a shop working primarily on piece work, the tendency is always to go to the extreme, and for the management to think it should get the same degree of service out of a quickly thrown up mold that it can from a carefully cast one. This does not follow and it will be found that day work is necessary at times.

There is one point that might be raised here. Is it always necessary to do all the reinforcing with iron that is customary? It takes time to place these iron pieces. We are inclined to think that a considerable

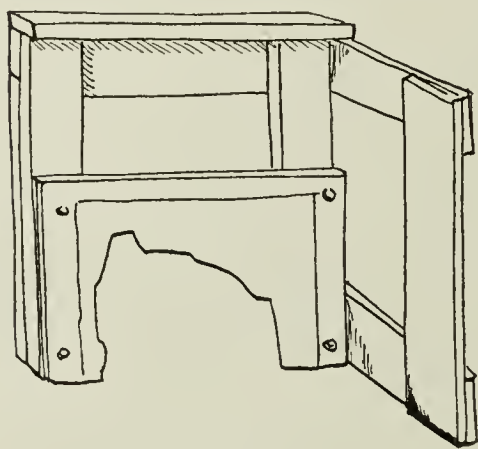


FIG. 1.

amount of iron work could be left out. Molds turning out from one to a few pieces need no such reinforcement, even when poorly made. When molds in other industries, with no iron, will stand the stamp of a machine plunger dozens of times surely a terra cotta mold can stand a few pressings. We are inclined to think that heavy iron work in all molds is a matter of habit, like a clerk using a slide rule who gets so that he multiplies 2×3 on the rule.

The making of a new horse mold for every template is another habit. A set of frames can be made up and the templates bolted in. (See Fig. 1.)

Machinery has never been developed to any great extent for the plaster shop though there are possibilities. The main machine remains the bench.

The importance of a level top cannot be too greatly emphasized. Usually the foreman is satisfied as long as the face of his piece is straight. But this is not enough. The bond must be straight also. Tops should be checked continually at regular intervals and dressed down accordingly. Level tops mean straight lines, right angles, and consequent saving of fitting costs.

There are a considerable number of things which the plaster shop can do that mean not only saving but better work in the finished goods, and these points should be most strenuously insisted upon. Slipshod work on the models means trouble and lots of it. Markings for spray lines, numerals, letters etc., should all be clean and clear cut. Time is saved all along the line then.

Molds which contain a number of pieces, such as panel molds, are often thrown up in a single piece and then sawed into the required number of pieces. This means an unsightly seam requiring a lot of extra finishing which is particularly bad in case of ornament.

Large heavy molds which are rolled over on account of the weight, and from which a considerable number of pieces are to be made, suffer a good deal of damage on the edge on which the turning is to be done. If a board is inserted along the edge, held in the plaster by nails having been driven in in slanting fashion, the turning will take place on the board and the mold will stand up indefinitely. (See Fig. 2.)

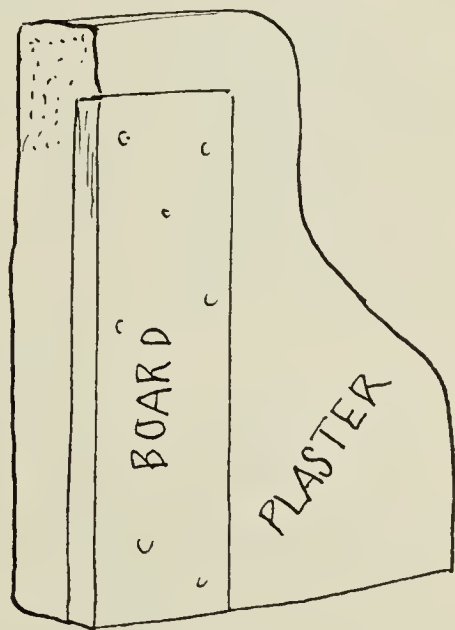


FIG. 2.

A prolific source of cracking along rebate lines, and wavy cornice lines is to be found in the manner in which the mold goes together, or the way it is taken apart. A large heavy cornice piece is sure to settle a bit when turned out of its mold. Suppose the mold is made in such a manner that the ends are the last pieces to come away—and this is usually the way a mold maker does the job—a glance at Fig. 3, shows that the end is heavily rebated and provision made for the outlookers. Naturally there is no chance for the clay to do any slipping and the ends are held rigidly against the end pieces of the mold. As a result the center of the piece between the two ends sags down. Also since the whole weight tends to rest on the rebate, a strain is set up resulting in cracking along the rebate line. The answer is to make the mold so as to remove the ends first, then the sides, and then the

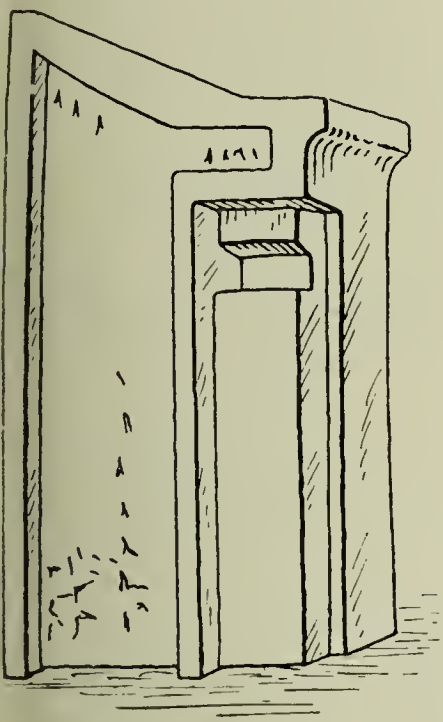


FIG. 3.

settle is distributed over the whole piece.

When pieces are faced on both sides as in the case of pilasters and columns, a good deal of difficulty is usually experienced in keeping exactly the same width for each piece if the mold is made in the ordinary way.

If the band iron does not happen to be tightly wedged, or if it slips a bit during the slugging, that piece will be a bit wider than it should be. Or a bit of clay may become gummed in where the sides and ends go together and result in the one end being a shade large, just enough to result in

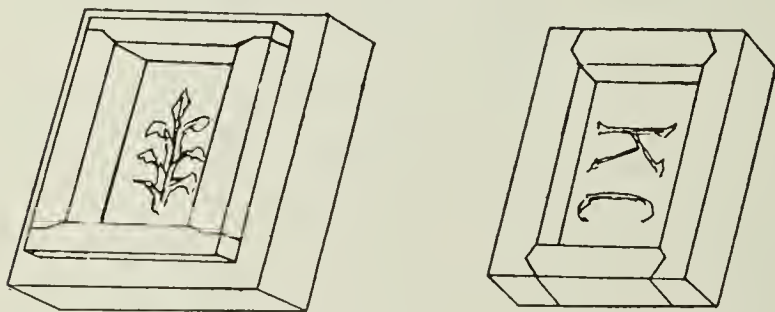


FIG. 4.

untidy looking work. The remedy here is the use of the case mold which is simply to cast or throw up an encircling case around the main molds (See Fig. 4.)

In general there is a tendency to do too much building of models where by the use of a little head work, the stuff could be handled on the running bench. If this point were watched more carefully a considerable amount of money would be saved in most shops.

The above items are a few illustrations of various little wastes and extravagances common to most plaster shops. There are many others and as can be seen by the method of dealing with those already described all that is needed by a foreman to pay his keep is a bit of common sense and ability to keep alive on his job.

NOTE: The authors wish to acknowledge their indebtedness to the Atlantic Terra Cotta Co. for permission granted in taking photographs and assistance in collection of data.

SHORT CUTS IN MITRE CUTTING

BY T. A. KLINEFELTER AND F. C. PARSONS

ABSTRACT

A discussion of the proper type of man to develop for mitre cutting, with hints as to quick and easy ways of doing the various processes involved in cutting and sticking mitres.

A department which is oftentimes much neglected, and not used to advantage is that of the mitre cutters. In proof of its standing in most shops, we believe we are safe in saying that very few plants pay the same rates and are as careful in the selection of their mitre cutters as they are in the care of their model makers. Yet, if anything, the reverse should be true. The chance for error is there although not so many pieces are as likely to be involved as in the case of a model maker's error. On the other hand he must handle thirty-five to forty pieces a day if he keeps his three finishers hustling as they should. So he must read his drawings much more rapidly, and just as accurately, as the model maker who does out about three pieces per day.

Again he must understand the handling of clays thoroughly so as to stick properly and get the correct shrinkage at the same time. And he must have brains to order his pieces properly so that those to be stuck together will be pressed the same day.

It is usually comparatively easy to break a mitre cutter into a model maker, but the reverse is not nearly so easy as it might appear. The loss of a mitre is costly in point of service, if nothing else. And the chance for loss is high in the case of poor sticking. Yet if mitres are properly made they should come through with a lower percentage loss than pieces which have been pressed by piece workers. The loss should never exceed $\frac{1}{2}$ of 1%.

The first factor entering into proper sticking is the selection of the clay. The stiffness or moisture content of pieces to be stuck together should be the same. Yet this is regularly neglected and cutters are trying to stick pieces together which were pressed on different days, or dried at different rates. This is perhaps one of the largest sources of cracks. Another source of trouble which often results in crazed ware is the practice of letting a lot of stuff accumulate on the floor, as happens when there is a rush of work, and wetting it down to hold it in shape. After a good soaking the surface is wet and sloppy while the inside remains hard and continues to harden. After getting through the kiln the glaze often shows craze on a piece of this type.

When it comes to the actual sticking, a good deal of carelessness is often the rule. It is very common practice to cut the mitre square and try to

do the cramming and working in an eighth-inch crack. Instead, the face should be left full so that the edges come together and the back beveled away quite fully so as to leave a large opening to cram and work. All the work is done from the back, the front remaining practically untouched. (See Fig. 1.)

Needless to say we are assuming that the surfaces have been well and thoroughly forked to provide a good welding surface and necessitate the

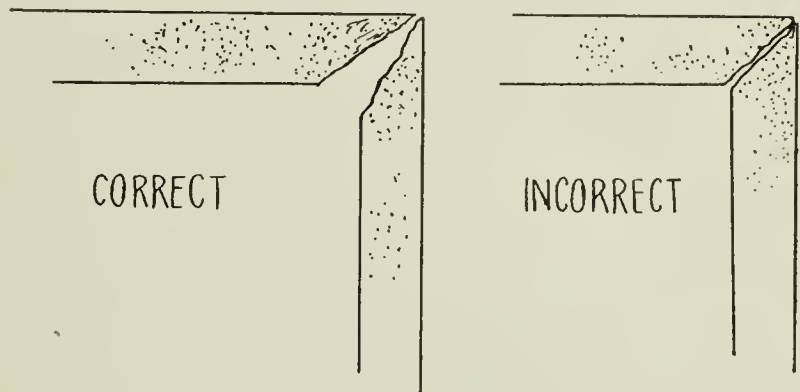


FIG. 1.

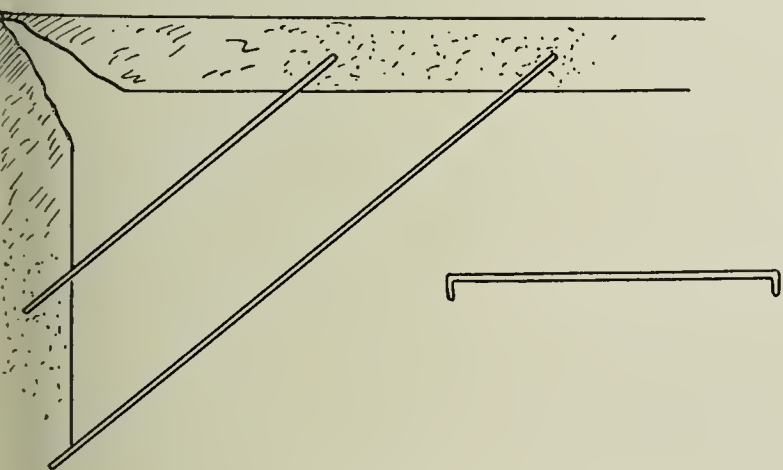


FIG. 2.

use of a minimum amount of water. While doing the sticking an exceedingly handy device is the use of a couple of iron clamps which can be stuck across the top of the pieces. (See Fig. 2.) The mitre cutter inserts

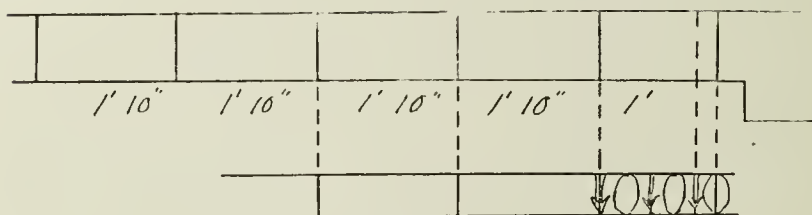


FIG. 3.

them just before turning the layout over to the finisher. The bottom edges are held on the board, of course. The clamps hold the top. The finisher can then work rapidly

with little danger of bungling and distorting his work. Several lengths made of $\frac{1}{4}$ -inch iron can be kept with the tools so as to be available instantly.

As the drawing office is primarily responsible for all clay work, it is here that someone must use headwork if the mitre cutting department is really worked to advantage. A great many models are often made up when a little clay work would do the trick and do it much cheaper. However, aside from that phase of the matter, a good deal of money is lost through lack of foresight if not boneheadedness. Take for instance running pieces of ornamental work: at the end of the course comes the mitre; next to the mitre a somewhat shorter piece than the regular running piece must be inserted. Will the draughtsman check up the ornament and see that his cut falls along the dart as it should? Generally not and the cut is likely to slice an egg squarely in two. This means that a modeler must get on the job and fix things up, perhaps spend hours at such work. A few minutes headwork would save the whole situation (See Fig. 3.)

Take another common practice in regard to sills of varying length. The usual way is to take a piece as long as the longest sill wanted and start slicing off the end to the size wanted, at the same time sticking on a corresponding width of stool.

Why not foresee this, and have a stool long enough to cover all cases, then slice off the stool for the longer pieces?

It is much easier to slice off than to stick. This applies to raised joint also. (See Fig. 4.)

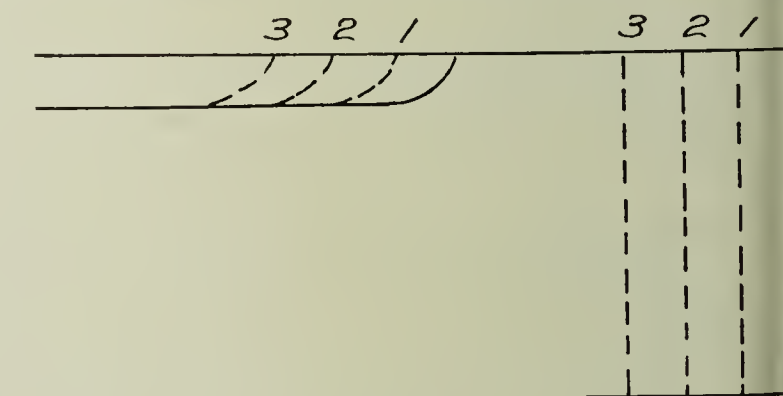


FIG. 4.

This brings up the point of the ordering of clay pieces by the mitre cutter. He should order his piece so that after cutting the ends will remain. Otherwise he must stick one end, which runs a chance of cracking. The composite mold such as is used in pressing voussoirs is an interesting illus

ration of how molds, money etc. can be saved by a bit of careful work.

A single mold with no chamfers, and an extra face can be used to make a whole flat arch. (See Fig. 5.) If the model maker lays out lines for every single piece and marks each line with its proper number, then the mitre cutter simply orders so many pieces out of each triangle number, the presser picks out the proper lines, makes his adjustment accordingly and delivers the piece. All the mitre cutter has to do is to set the pieces all together, to form the complete arch thus checking them all at once.

A device that is a big time saver is the use of a tin template when dealing with odd sized angles.

The common practice is to keep checking the bevel square on the full size. If a good sized template is cut out it can be used throughout the job without stopping to check.

If a mitre cutter is of the proper type and training and continually on the lookout for saving time and expense on such matters as the above, the mitre cutting department becomes an exceedingly valuable adjunct and money saver.

NOTE: The authors wish to acknowledge their indebtedness to the Atlantic Terra Cotta Company for permission granted in taking photographs and assistance in collection of data.

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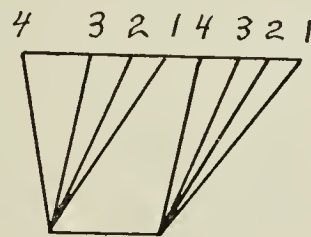
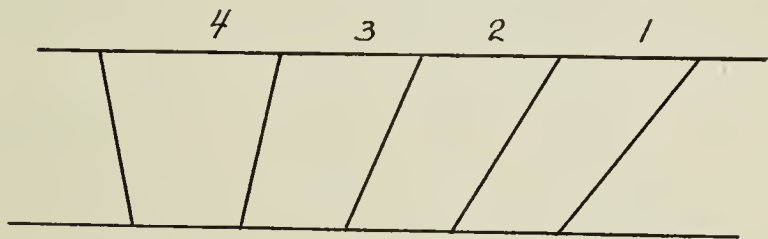


FIG. 5.

THE USE OF BENTONITE FOR SUSPENDING ENAMELS¹

By M. E. MANSON

ABSTRACT

Bentonite, a highly colloidal clay, has a much greater suspending power than the ordinary enameling clays. One part of bentonite is equivalent to five parts of clay. Its use enables the enameler to reduce the amount of raw materials necessary to add to his frit. Some disadvantages are pointed out.

Introduction

Within the past three years, considerable interest has been exhibited in the material known as "bentonite." This name has been applied to a certain type of clay-like mineral having very peculiar physical properties. The material has no fixed chemical composition, and samples from different localities may vary widely in color and fracture. Its distinguishing characteristics are its colloidal properties, its peculiar ability to absorb several times its weight of water and its soapy feel when wet.

Although the material has been known for many years, its use was very limited until 1920. Probably its chief use during this period was as a base for the medical dressing, "antiphlogistine." Since 1920, however, as a result of investigations by several organizations, including the Forest Products Laboratory at Madison, Wisconsin, many uses have been found for bentonite. Those who may wish further information concerning this remarkable material, are referred to a bulletin issued by the Bureau of Mines.

In the present paper, its adaptability to use as an enameling clay is taken up. The only property of the bentonite investigated was its ability to keep enamel suspended in water. The experiments with ground coat for dry process enameling were conducted at the plant of the Rundl Manufacturing Company, those with wet process ground and cover coat at the plant of the A. J. Lindemann-Hoverson Company. Both plants were using enameling clays which are well known to enamelers, and it was against these that the bentonite was compared. Throughout this paper the enameling clays used are referred to simply as clay, while the bentonite is referred to by name.

Use in Ground Coat for Dry Process Work

As a preliminary test, 20 grams of white enamel powder, 100% through 60 mesh, were placed in each of two glass tubes, with 20 cc. of water. To one tube 5% clay was added, to the other an equal amount of bentonite. Both tubes were shaken vigorously for ten minutes then allowed to stand and the time required for settling noted. The tube with clay was completely settled in four hours. The tube with the bentonite had not begun to settle at the end of three weeks, at which time it was cleaned out.

¹ Presented before the Enamel Division, Pittsburgh Meeting, February, 1923.

² R. B. Ladoo, "Bentonite," Bur. Mines, Repts. Investigations, No. 2289.

This rough test indicated that the bentonite had a very high flotation power, and immediately suggested that satisfactory results might be achieved with much less clay than is required when using the ordinary enameling clays. Before proceeding with laboratory tests, a regular factory batch of ground coat was ground, keeping all weights the same, but substituting bentonite for clay. The batch consisted of frit, 200 pounds, borax 4 pounds, water 100 pounds. In our standard practice, using $2\frac{1}{2}\%$ of clay, the finished product was fairly fluid, requiring just a little thinning for use. This experimental batch, at the end of grinding, was of the consistency of soft butter, and would not flow out of the mill. It was necessary to add again as much water to bring it to the proper consistency.

A series of laboratory tests was now run, using a small pebble mill for grinding. The general scheme was as follows. In each case 200 grams of frit and four grams of borax were taken. Clay was varied from five grams to one gram, or $2\frac{1}{2}\%$ to $\frac{1}{2}\%$ and sufficient water was added so that the final product had approximately the same consistency in each case. Consistency was determined by a viscosity or mobility test, in which the time required for 25 cc. to run out of a 25 cc. pipette with a large orifice was noted. An arbitrary figure of five seconds was taken as standard, since ground coat at this viscosity seemed about right for use. The results are given in Table I:

TABLE I

Test No.	1	2	3	4	5
Frit	200 gms.	200 gms.	200 gms.	200 gms.	200 gms.
Clay ¹	5 gms.	5 gms.	3 gms.	2 gms.	1 gm.
Borax	4 gms.	4 gms.	4 gms.	4 gms.	4 gms.
Water	120 cc.	230 cc.	160 cc.	145 cc.	135 cc.
Viscosity	$4\frac{4}{5}$ sec.	$3\frac{1}{5}$ sec.	5 sec.	5 sec.	$4\frac{4}{5}$ sec.

¹ Clay used in No. 1, bentonite in all other tests.

After determining the viscosity of each batch, 50 cc. was poured into a glass tube, and the amount of settling noted. This was expressed in percent of the height of clear water visible to the total height of the material in the tubes. At the end of two days, Numbers 1 and 2 had settled about 7%, while 3, 4 and 5 had settled about 3%. Scarcely any further settling took place in any of the tubes after the first two days. As is evident from the viscosity determination in test 2, too much water was added to it. Had its viscosity been 5 seconds, I believe there would have been even less than 3% of settling.

The above tests indicate that there are two methods of using bentonite. One can use the same amount of clay, and get a greatly increased volume of enamel or one can use a great deal less clay to get the same volume of enamel. The second method would seem the more desirable, inasmuch as a certain volume of enamel is usually applied to a piece, and in the first

method this volume would contain much less enamel by weight than in the second.

With this information, a plant test was made in which ground coat ground with 1% bentonite was compared with the same frit ground with 2½% clay. Accurate burning tests showed that the ground coat with bentonite was a trifle softer, or more fusible than the other, but when the bentonite ground coat was used exclusively over a period of three weeks, there was no noticeable difference in the quality nor amount of ware turned out. On the other hand, the ground coat stayed in suspension much better than it had ever done before. Since the cost was about the same in each case, we came to the conclusion that the advantage lay with the bentonite.

Use in Wet Enamel on Steel

As mentioned above, this work was carried on at the plant of the A. J. Lindemann-Hoverson Company, and was under the supervision of Mr. Atkinson of that company.

In their standard practice, ground coat for sheet steel is ground with 5% clay. When bentonite was substituted, they found it necessary to make a drastic cut in the percentage used. This percentage was therefore reduced by progressive stages, until 1¼% was finally chosen as being about right. This checked our own experience, showing that one pound of bentonite was equivalent to five pounds of clay. Operations with this ground coat were, however, not wholly satisfactory. While its consistency was the same as the standard, there was a difference in the working properties. In using the standard batch, a coated piece would drain for a moment, and then apparently "set," or congeal, on the ware. On the other hand, the ground coat with bentonite would drain nearly indefinitely, if allowed. The reason for this is not clear. It is possible that the "set" occurring in the standard ground coat is due to rapid evaporation of water from the surface of the piece, while the very great affinity of bentonite for water prevents such evaporation.

There was an added difficulty, in that it was nearly impossible to thicken a batch which accidentally became too thin. Ordinarily if a batch became thin, it was allowed to stand overnight when the excess water could be skimmed off the top. With the ground coat containing bentonite, no amount of standing ever brought any water to the top; attempts to thicken it by introducing some very thick ground coat were not very successful due to the great difficulty of getting a thorough mixture of the two lots.

This is a record of the chief faults of the material in Mr. Atkinson's estimation. It would seem to the writer, however, that the absence of settling where bentonite is used might, in some circumstances, be more of a virtue than a vice.

In order to secure some of the advantages of the bentonite, without it

disadvantages, a series of tests was run, using a combination of bentonite and clay, the combination finally chosen being $2\frac{1}{2}\%$ clay, plus one-half per cent of bentonite. This worked fairly well and is, I believe, in use now, but its advantages are doubtful.

It would appear to the writer that the greatest field for bentonite would lie in the wet process finish coats, especially white coats. Generally, from 8% to 14% of raw material is added to the frit in the mill, of which 5% or 6% is clay. Since this raw material has no gloss itself, its presence in the frit must have some effect toward reducing the gloss of the finished piece.

Anything which would reduce the amount of raw addition to the frit, would therefore seem very desirable. One test of this idea was made, with a white enamel for sheet steel. According to Mr. Atkinson, the gloss of the resultant enamel was seriously impaired, instead of being helped. In fact, the results were so unfavorable, that no more work was done along this line. This report, so entirely opposite to that expected, led the writer to make up some test pieces in the laboratory, of white, wet enameled cast iron. Enamel ground with 5% clay was compared with the same enamel ground with 1% bentonite. There was very little difference in the gloss of the two enamels, but if anything, the bentonite enamel had the best appearance. This would lead one to believe either that some enamels are adversely affected by the bentonite while others are not, or that something else caused the trouble with the steel enamel.

Conclusion

From the few experiments just outlined, it seems evident that by using bentonite as an enameling clay, the amount of raw addition to an enamel can be greatly reduced. Theoretically, the finish of the resultant enamel should be improved, although further experimentation may disprove this. Even in the small amount necessary, bentonite has a greater suspending power than other clays, which should be of advantage to those enamelers who coat with spray guns. But difficulties of manipulation are apt to turn up, which may more than offset the advantages of the material. This paper does not pretend to more than scratch the surface of the subject. Should others investigate further, they will no doubt discover many facts which we have overlooked.

The bentonite used in this work was obtained from the American Colloidite Company of Chicago, who market it under the trade name, 'Colloidite.' For other sources of supply see the Bureau of Mines, *Bulletin*, mentioned above.

NOTE: The writer wishes to express his appreciation of the coöperation given by Mr. W. C. Lindemann.

RUNDLE MFG. CO.
MILWAUKEE, WIS.

VITREOUS ENAMELING WITH ELECTRIC HEAT¹

BY E. F. COLLINS

ABSTRACT

This paper is descriptive of the suitability of the metallic resistor furnace for the application of vitreous enamels. Comparisons are made with fuel fired furnaces. Uniformity and perfect fusion of enamel results from the high grade temperature control of the electric furnace. Atmospheres vitiated with products of combustion can not be present in the electric furnace to give defective coatings. Examples of operating furnaces for watch dials and for bath tubs are given and the average performance, in time and input, for bath tub furnaces. It is believed by the author that the electric heating process can not long be considered as anything but the most economical over all, and its standardization for this purpose will eventually result.

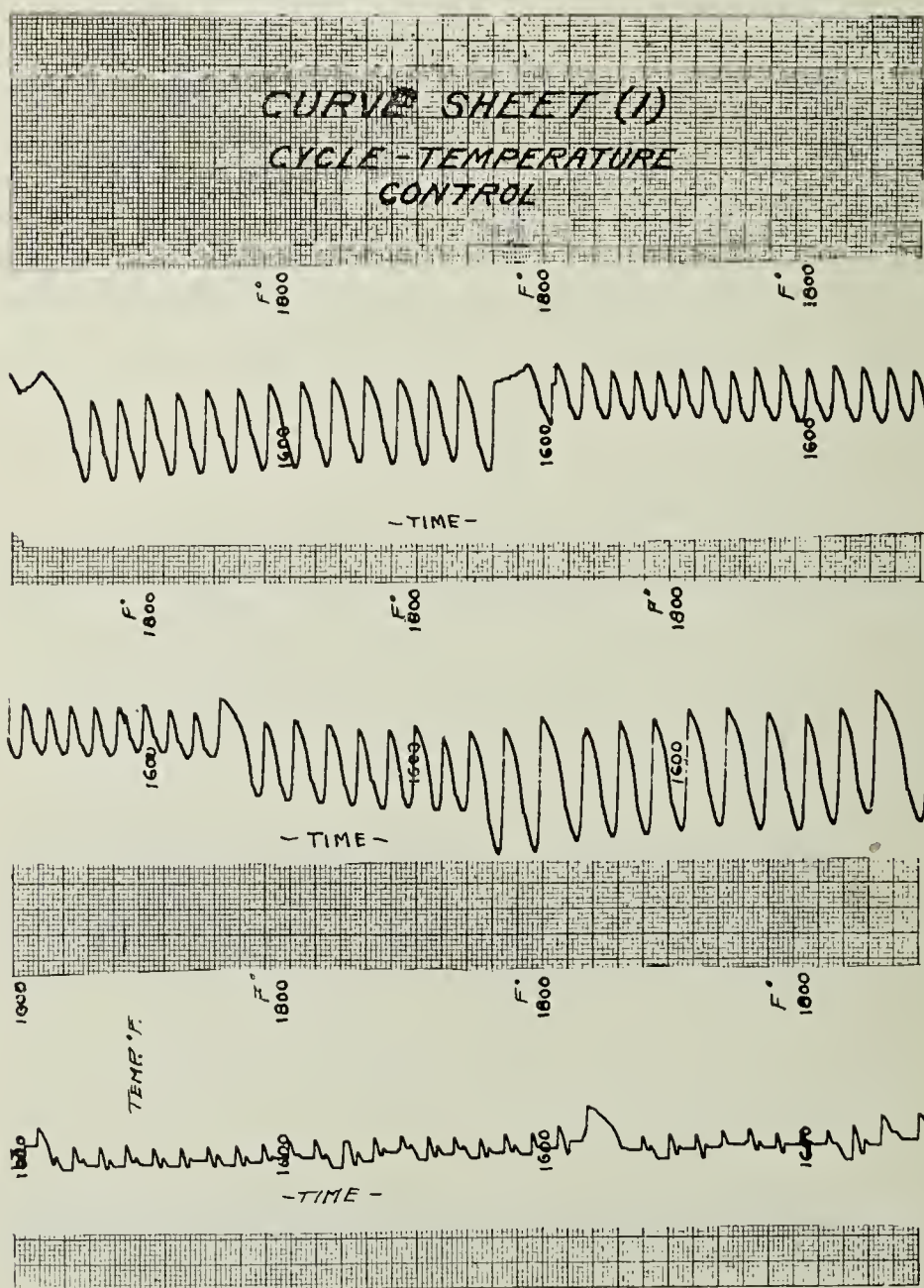
The enameling of metals is a relatively old art and had its beginnings prior to 1300 B. C., when the Assyrians and Egyptians used it in decorations

for palaces and gifts. It has in the last few years developed into a modern industry of no mean size. The modern industry includes not only the manufacture of decorative materials but also the productions of enameled sheet steel and cast iron wares, considered as modern standards of durable and sanitary equipment in universal use.

Vitreous enamels are simply glasses with low melting points, fused to the surface of metals or anything which will withstand the fusion temperatures.

There are four general methods for applying the slip or enamel in

preparation for baking it upon metal: first, slushing, or dipping the ware into the slip and the shaking it to give a uniform coat; second dipping and then permitting to drain; third, spraying for complex shapes



¹ Presented before the Enamel Division, Pittsburgh Meeting, February, 1923.

and even flat simple shapes; fourth, dusting or dry process, used generally on cast iron and heavy steel shapes. This process is used for bath tubs, sinks and similar ware.

Several types of furnace have been used in the past for the baking or burning of enamel ware. These differed mainly in the method of heating. When gas is used a semi-muffled heating chamber may be employed, but when coal or fuel oil is used then a full muffle is necessary.

One essential feature in the furnace is uniformity of temperature throughout the furnace, even though the flow of heat is decidedly different and varies in different parts of the baking chamber. Uniformity of temperature depends upon the type of furnace used and upon its design.

Within the past four or five years the electric furnace has steadily and continuously demonstrated that it is without a peer when the results from its use in baking vitreous enamel are compared to fuel fired furnaces. In this type of furnace the control of heat flow is so complete that uniform temperature may be applied in baking a complex shape, even though the heat flow or heat quantity varies in different parts of the charge. I refer to such parts as apron bath tubs. Here no difficulty is met in delivering the required amount of heat at the same temperature on either the apron or reverse side of tub. Such manipulation of heat is, of course, impossible with other than the electric furnace.

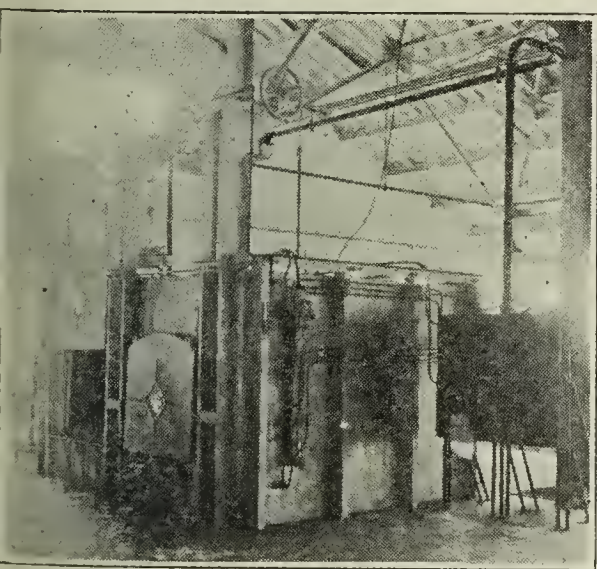


FIG. 2.

with automatic control of temperature and operate at temperatures of 1900°F or better, which cover the ordinary requirements of 1800°F for ground coat, 1750°F for first finish coat and 1600°F for finish coats.

Due to the perfect heat control in these electric enameling furnaces, they

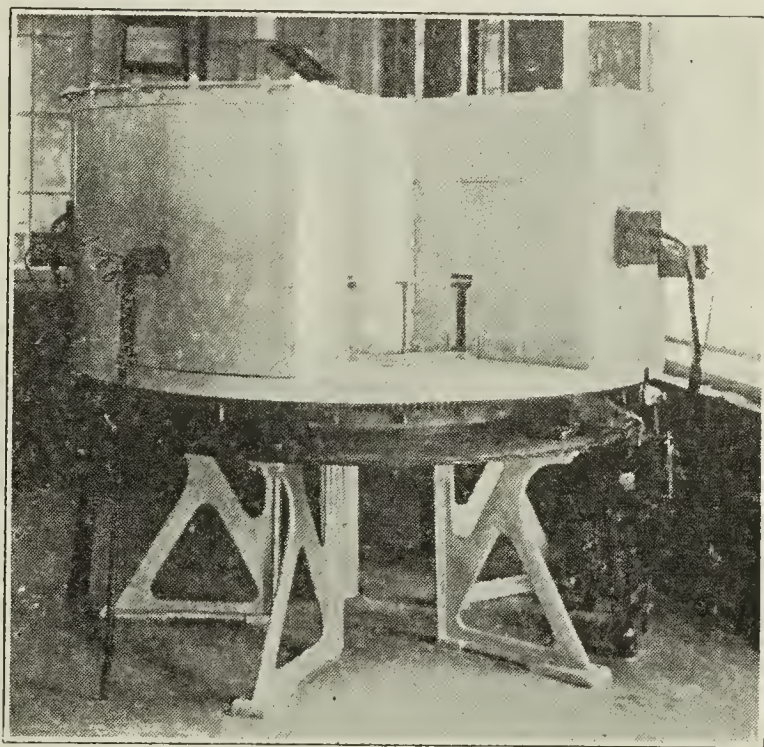


FIG. 1.

The metallic resistor type of electric furnace is the one with which this paper deals. Such furnaces are equipped

show a greater output for the same furnace hearth than the fuel fired furnace. The time of burning is dependent upon the cooler portions of the fuel furnace and a compromise must be made between hot and cold portions of the furnace which may result in some parts of the charge being slightly under-fired and other parts being slightly over-fired. If the furnace has large variations the ware must be turned.

Strictly speaking, to insure a uniform product, the furnace must be capable of maintaining a constant operating cycle of temperature rather

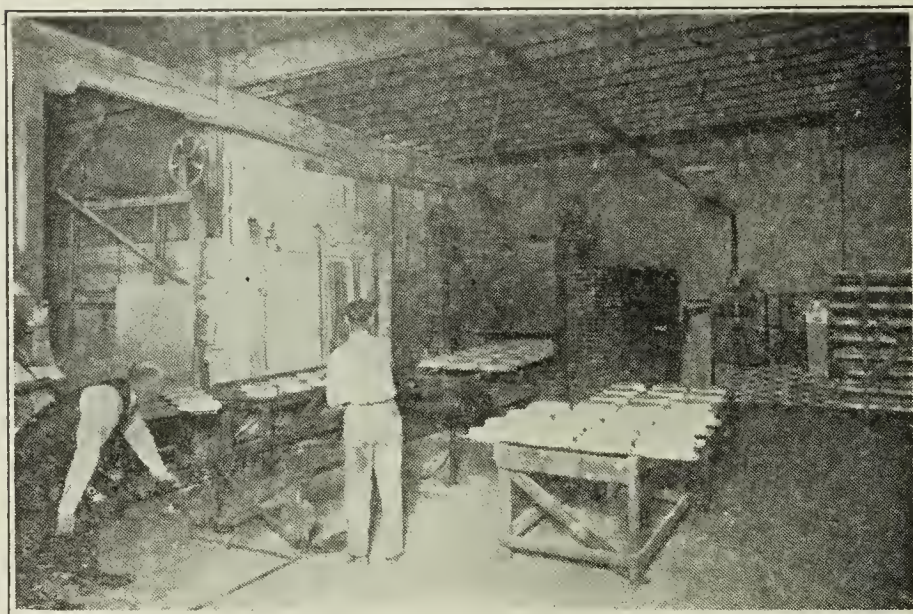


FIG. 3.—Vitreous enamel furnace working chamber, 10 ft. deep, 4 ft. wide, 2 ft. high. Connected load 140 kw., 220 volts, 3 phase, 60 cycle, 1700°F operation. St. Louis Brass Company, St. Louis, Mo. Firing vitreous enamel at 1650°F.

than a constant temperature, *i. e.*, during the normal working of the furnace the temperature will vary from the maximum just before charging, followed by a sudden drop in temperature when the furnace is charged, which again rises as the charge becomes heated.

If this cycle of temperature can be made to occur regularly and identically, then the furnace has a controllable temperature.

suited to the work of vitreous enameling. Such performance is shown on curve sheet (1). This chart shows uniform cycles of temperature for light and heavy work in the electric furnace.

In addition to temperature control the electric furnace is possessed of a long life and low power consumption.

Sulphur fumes which are injurious to enamel ware are absent in the electric furnace, and hence its use secures against high percentage of rejections from this cause.

Again the electric furnace has no muffles to give trouble, such as is experienced with coal and oil firing.

The electric furnace has been able to handle 170 heats in 10 hours against 130 heats with the coal fired furnace. Heats have been completed in 50 seconds that would require 3 minutes and 40 seconds in the oil furnace.

It is desired to call attention here to a few installations of the electric furnace for the baking of vitreous enamel. These furnaces range from one which is enameling watch dials to those handling the largest size of bat-

tubs, and they have shown to be uniformly satisfactory for all classes of work on which they have been used.

In Fig. 1 is shown a furnace for enameling watch dials. Mean diameter of hearth is 3 feet, width of hearth is 2 inches. Heat is furnished by 30 kw. metallic resistors. Production is 15 dials per minute. This furnace is reported as saving \$50.00 per day in labor charges alone. The output of dials is essentially 100% perfect as against 40 to 60% good dials in the combustion furnace which it replaced.

In Fig. 2 is shown a larger type such as is used on bath tub enameling. It has for dimensions a heating chamber 9 feet long, 5 feet 3 inches wide and 4 feet 3 inches high, and is equipped with 200 kw. resistors. A furnace of this type is guaranteed to produce four tubs per hour with a kw. consumption of 50 kw.-hr. per tub. In other words, the user of such a furnace may expect a production about as follows:

On 4 $\frac{1}{2}$ foot, 5 foot and 5 $\frac{1}{2}$ foot rolled rim tubs the burning time for a complete tub will vary from 13 minutes to 17 minutes. This is the time for what is commonly known as three coat work, namely, one ground coat and two white coats.

The average output per furnace of the above sizes is about 4 tubs per hour with an energy consumption somewhat less than 50 kw.-hr. per tub.

The average output of the above sizes is about 4.09 tubs per hour at a cost of 48.96 kw.-hr. per tub for each furnace.

In Fig. 3 is shown a vitreous enameling furnace with baking chamber 10 feet deep, 4 feet wide, and 2 feet high. This furnace has been operating more than two years and the users report that it is superior in many ways to the fuel fired furnace formerly used by them. They state that the "over-all" cost of product is less than for the fuel fired enameling furnace. The upkeep has been practically nothing compared to the cost of upkeep of coal or oil fired furnaces doing the same duty.

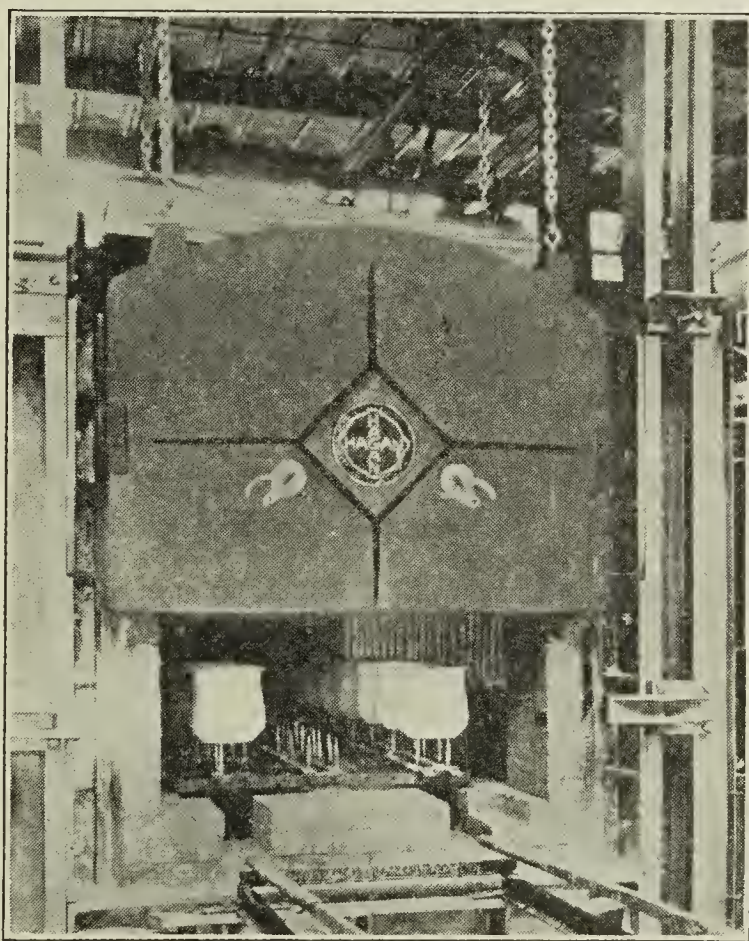


FIG. 4.—End view double chamber electrically heated vitreous enameling furnace, Coonley Manufacturing Company, Cicero, Ill. Each chamber, 8 ft. long, 42 in. wide, 2 ft. high. Connected load of each chamber 117 kw., operating temperature 1750°F.

In Figures 4 and 5 are shown views of a furnace operating on enamel ware of the lighter domestic class. Here again the manufacturer using it speaks highly of its performance and states that its use gives a lower "over-all"

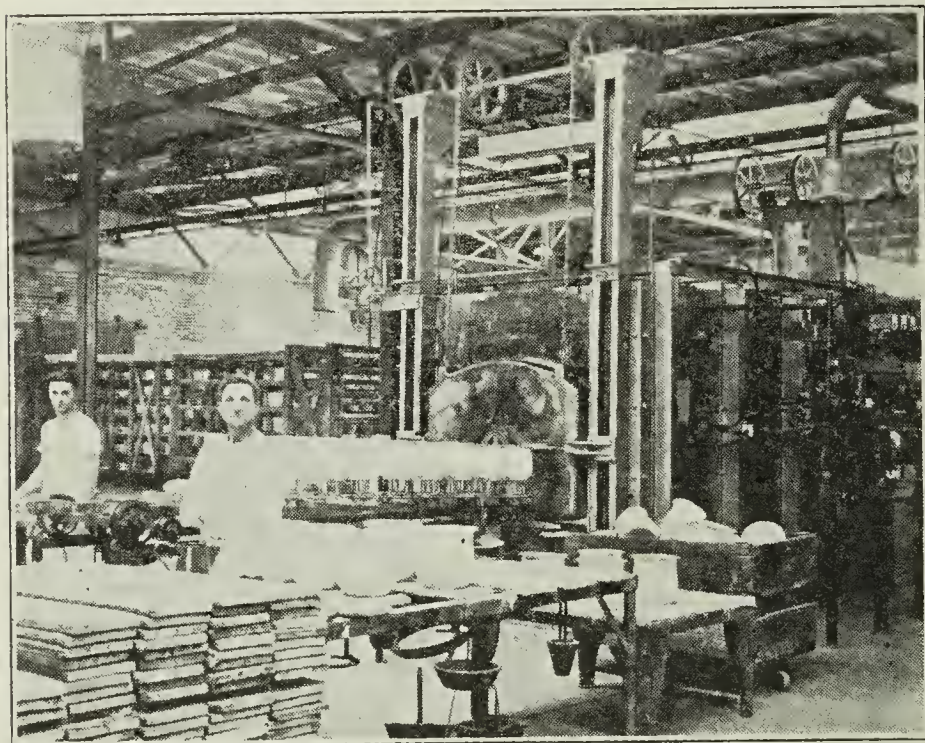


FIG. 5.—Double chamber electrically heated vitreous enameling furnace, Coonley Manufacturing Company, Cicero, Ill. Each chamber 8 ft. long, 42 in. wide and 2 ft. high. Connected load for each chamber 117 kw., operating temperature 1750° F.

cost for his product than did the coal or oil fired furnace. Better working conditions especially in hot weather are given by the user of this furnace as a great advantage.

The writer hopes that what he has said here will encourage those who have not done so to investigate the merits of the electric metallic resistor furnace for vitreous enameling. He sincerely regrets that he is unable to present, at this time, more definite data regarding all installations recently in-

stalled as well as all those which have been operating for many months.

Much data of this nature has, however, been rather jealously guarded by several who have used this type of furnace, for the reason perhaps that they are not anxious to have their competitors realize too soon the advantage they have secured for themselves through the use of the electric furnace. It is hoped, therefore, that these few statements concerning the electric furnace may determine others to decide that they will not longer be denied the aid which electric heat offers in this vitreous enamel process.

GENERAL ELECTRIC COMPANY
SCHENECTADY, N. Y.

PRODUCER GAS FOR BURNING REFRACTORIES¹

By W. D. RICHARDSON

ABSTRACT

History of installations in the United States of producer gas for burning fire brick. Causes of failure or abandonment of producer gas firing. Continuous regenerative kiln necessary for successful burning at high temperatures with producer gas.

The compartment kiln, fired with producer gas, best adapted for general refractories. Advantages of the compartment kiln over the car tunnel kiln. Essential features of continuous kilns for the successful burning of refractories. Special features of gas producers for ceramic kilns.

Temperatures from producer gas. Economy of producer gas as compared with natural gas, oil and powdered coal. Investigation of designs and methods of operating gas producers.

Introduction

It has now become quite generally recognized by engineers of metallurgical plants that producer gas has a wider application in operations requiring high temperatures and is more efficient and economical than any other kind or form of fuel. Hence, the gas producer is almost universally found in steel works and glass factories. Moreover, probably in no country has the gas producer been so highly developed as it is in the United States of America. The question naturally arises then, why is not producer gas more extensively used in the clay industries, especially for high temperatures?

The literature of our SOCIETY contains several papers on producer gas, but none on the application of this fuel to the burning of refractories. In Europe, producer gas has been successfully used for more than forty years in the burning of high grade fire brick. In this country, several trials have been made of producer gas in fire brick plants, but for one reason or another the results have not been satisfactory, and the kilns or the gas producers have been torn down or abandoned. So far as I know, producer gas is not in use today in this country for the burning of fire brick. It may be interesting to give a brief account of the installations of gas producers in fire brick plants in this country, so far as I have myself observed or record of which I have been able to find.

Historical

The first use of producer gas in the burning of fire brick in America, that I know anything about, was at the Mount Savage Fire Brick Works. There were two tunnel kilns (not car kilns) fired with producer gas for about twenty years, from 1890, or a little before, to 1908. The suction gas producer was on a car that was moved back and forth on a track on one side of the kiln. The gas was conducted by sheet iron pipes to the ports

¹ Presented before the Refractories Division, Pittsburgh Meeting, February, 1923.

in the top of the kiln. When first installed, these producers were charged through bell hoppers on top, but when I saw the kilns in operation, in 1904 and 1905, the bell hoppers had been removed and the producer was charged with a shovel through a door in one end. In fact, the producer was nothing but a big oblong stove with a thick fuel bed on a cast iron grate. The gas, being fired at the top of the kiln, of course would not burn the brick hard to the bottom, so coal was also fired through holes in the top, in the usual manner.

Mr. J. P. Biays, Vice-President of the Union Mining Co., writes, "As long as the foreman, who was at Mount Savage when I went there in 1901, lived the kilns were operated with comparative success. After his death, the operation of the kilns was not considered successful and they were done away with."

The first producer gas-fired kiln that I ever saw was at a plant of Harbison-Walker, near Pittsburgh. There were two kilns in operation there from about 1894 to 1902—a Dunnachie kiln of ten chambers and a Mendheim kiln of twelve chambers. As my visit there was only for an hour or two and as I then knew practically nothing of producer gas nor of continuous kilns, I have no distinct recollection of the equipment nor of the results obtained.

Mr. James Dunnachie, Glenboig, Scotland, in his paper before the English Ceramic Society in 1908 on "The Dunnachie Continuous Regenerative Gas Kiln," gives a letter from Harbison-Walker Refractories Co., from which I will quote:

As far as the consumption of coal is concerned, our saving of fuel with these kilns amounts to 40 or 50 per cent over the ordinary or old form of direct fired kilns. Several years ago we sold the plant at which these kilns were located, and have not constructed any more of them, for the reason that repairs on the gas form of kiln are considerably greater than those on the old fashioned or ordinary form. In addition to this, the interest charge on the first cost is at least double that on the old form of kiln. We found that these extra repairs and extra interest cost amounted to as much as our saving in fuel.

This simply means that the gas kilns are not an advantage where fuel is extremely low. For instance, at the time we were using your kiln, we were buying coal at 60 cents a ton delivered at our works. Forty per cent saving of fuel at this price does not amount to much, but if we had been paying two dollars and upwards the saving, as you can easily figure out, would amount to several times more. Therefore, where fuel is high priced, the gas kiln is a great advantage over any other form we know of and, as previously stated, we would decidedly prefer your form of construction.

On this letter Mr. Dunnachie comments as follows: "What the writer says about the cost of repairs surprises me. My experience is that gas firing is much easier on the brickwork than coal firing."

I will say also that my own experience, as well as that of others in this country, is to the effect that producer gas damages a kiln much less than

direct coal firing. A battery of rectangular chambers, however, unless properly designed and built, may cause excessive repairs from expansion and contraction of crowns, especially if fired only on one side.

The next producer gas-fired kiln that I know of in a fire brick plant was built at the works of the Christy Fire Clay Co., about 1905. This was probably designed after German plans, as the drawings were made by Mr. Geo. Vater, who was a graduate of a German Ceramic School and had had some experience in fire brick works at Grosalmerode. Though I recommended Mr. Vater for this job, he having worked for me as a draftsman, yet I did not see the kiln until the visit of our SOCIETY to the plant in 1908. I do not remember much about the kiln, except that it was the old Siemens Gas Producer in a pit below the surface of the yard and that the gas came into the kiln through the floor. We know now that the kiln could not have served its purpose well and we think it was in operation only a few years. Answering my letter for information about this, Mr. R. D. Hatton, Vice-President and General Manager of the Lehigh-Christy Clay Products Co., writes: "The Christy Fire Clay Co. had build a continuous gas tunnel kiln some years ago, which, as far as we recall, was planned and designed by Mr. Vater in collaboration with Mr. Miller. Our records are incomplete, in fact we are unable to trace any record as to results of this installation, but you have made a correct statement that we did tear the kiln down."

In 1918 I was doing some work for the U. S. Shipping Board at the fire brick works of the Didier-March Co., Keasby, N. J., and saw there a large producer gas-fired continuous kiln, which had not been in use for some time. This kiln was of German design and the mechanical producers were made in Germany, in fact the whole plant was 100 per cent German, and had been taken over by Palmer. I could get no information of their experience with this kiln, but it evidently was not satisfactory, or such a costly installation would not have been abandoned. My impression is that the kiln, which has since been torn down, could have been modified to give very satisfactory results.

Causes of Failure

Evidently no single cause can be given for the failure or abandonment of these attempts to use producer gas for the burning of fire brick. In some cases, undoubtedly, the gas producer caused a lot of trouble, but in most cases, the method of conducting the gas into the kiln and of distributing and regulating it was faulty, and probably in all cases there was a lack of practical knowledge of the generation and application of producer gas to the burning of clay products. Moreover, it should be noted that in those days there was not available the controlling apparatus that is now so extensively used. In general, it may be said that the pioneers in any

improved process are sure to have troubles and few there are who persevere until these troubles have been overcome. This does not mean that all attempts in this country to burn fire brick with producer gas have been failures, so far as obtaining good burns, but that under past conditions of cheap fuel and cheap labor continuous kilns and gas producers may not have been the most economical equipment.

Progress

We have learned a lot about the construction and operation of gas producers since then and, what is more important, we have learned how to construct a continuous kiln for the burning of producer gas. This increased knowledge is not due to the work of any one man, but has been gradually developed from the work of many, as the records of the Patent Office show. Looking over these patents, with the light of our own experience, we see some good features in nearly all of them, but most of them lack some feature essential to practical success, and most of them, fortunately, never got beyond the Patent Office, that is, no one sunk any money trying them out.

The Compartment Kiln

All know that for attaining high temperatures, such as are required in the fire brick industry, producer gas must be served hot, not only must the gas be hot as possible, but the air for combustion must be hot. These conditions can only be successfully met with the continuous regenerative compartment kiln. To be sure, with proper recuperation and insulation, high temperatures can be attained in periodic kilns, and, under certain conditions, this may be practical, but, with the compartment kiln that we have today, the periodic kiln should only be used on small plants or for special requirements.

The Car Tunnel Kiln

But what about the car kiln? This form of continuous kiln is being most vigorously promoted and its development is being watched with much interest by all clayworkers. It undoubtedly is the ideal kiln and will be used more and more in the clay industries, but its use is likely to be retarded somewhat by the promoters who recommend it for every condition and purpose. The fact should be kept in mind that no single form or type of kiln is, or every will be, best for all conditions and purposes.

There are certain inherent disadvantages that, I believe, will always keep the car kiln from being as suitable for general refractories as the compartment gas kiln. Some of these are:

1. In a car kiln the products should not vary greatly in size, so that the

time required in heating up, soaking and cooling down of every car will be practically the same. In the fire brick industry it is often necessary to turn shapes varying a hundred pounds or more in weight. In the compartment kiln the separate chambers may be set with different sizes and kinds of ware and the gas easily regulated so as to give every chamber the requisite time and temperature for best results.

2. It is economically necessary that the time of cooling the car kiln be rapid. The compartment kiln is designed for slow cooling, which is sometimes desirable for large bodies.

3. To make the car kiln economical for heavy clay products, the cars must be fairly wide and, as the fires must be on the sides of the tunnel and the draft longitudinal, there must be considerable difference in temperature from the sides of the car to the center, and no system of cross firing can entirely overcome this. To be sure, this may be largely overcome by a weak draft and a reducing fire, but in burning fire brick, oxidizing conditions are generally desirable. Even if the cars pass through a muffle, this remains true to a certain extent, and it is a question whether the muffle kiln is not too costly, in construction and upkeep, for general refractories.

4. In the car kiln, when repairs are necessary, the operation of the kiln must cease entirely, while in the compartment kiln there need be no shut down for repairs and generally repairs can be made without interfering with the regular operation of the kiln.

Personal Experience

My experience with producer gas began in 1910, when I was called to take charge of a face brick plant having a Youngren Compartment Kiln. My early struggles with this kiln were related to the SOCIETY and can be found in Vol. 14 of the *Transactions*.¹ Though I had not at that time made changes in the kiln or gas producer, yet I then made the statement in my conclusions, "This type of kiln is the best that I have ever used for the burning of face brick." Since then I have, as superintendent, manager or consulting engineer, had almost constant experience with producer gas and the compartment kiln, and have been able to make such improvements in gas producers and compartment kilns for producer gas fuel that I have become convinced that producer gas is the most practical fuel today in most situations and is *the* fuel of the future.

Though I have never used producer gas in the burning of refractories, yet I have used it in the burning of face brick from a clay requiring as high heat to produce a hard body suitable for facing as is used in most fire brick plants. Our light-buff, dry-pressed face brick at Hebron were burned to cone 8 and to cone 10 in the bottom, two courses above the

¹ *Trans. Amer. Ceram. Soc.*, 14, 778 (1912).

floor. Our coal was Dakota lignite, from which we generated gas and fired a compartment kiln of my own design, compartments 18 ft. wide by 43 ft. long and 10 ft. high, inside measurements, holding about 65,000 standard brick. The kiln was designed for burning a compartment every 48 hours. Our regular time of burning was 36 hours, but the burner occasionally got in a hurry and finished a compartment in 24 hours by putting down cone 10 on the bottom.

The Continuous Kiln for Refractories

All will admit that the principle of the continuous kiln is absolutely correct. With the knowledge and experience that we now have, this economic principle can be applied successfully to the burning of refractories. I want to specify certain features that must be recognized and followed in order to attain the desired results:

1. The kiln must be a compartment kiln or a car tunnel kiln.
2. The compartment kiln must be fired with a gaseous fuel, from coal or oil.
3. The compartment kiln must be down-draft and fired from both sides of the compartment. The gas and air, in proper proportions, must be mixed in combustion bags, close together. The floors must be perforated so as to secure an even distribution of heat.
4. The gas must be brought to the kiln in underground ducts, well insulated from moisture, and evenly distributed to ports in the bottom of the combustion bags, underneath the air. The distribution of the gas must be under perfect control by valves within easy reach of the burner while he is looking in the peep hole on a line with the tops of the combustion bags.
5. The gas must be brought to the combustion bags as hot as possible without superheating other than is given by the distribution ducts in the kiln.
6. The air for combustion must be as hot as possible and the amount easily regulated.
7. It should not take more than 48 hours to burn to the highest temperatures desired, in every part of the compartment.

Gas Producers for Kilns

There are now some good gas producers on the market, both hand-stoked and mechanical. The advantage of the mechanical producer is chiefly in its greater capacity per square foot of area of fuel bed. A good hand-stoked producer will gasify 10 to 15 pounds of coal per square foot per hour. A mechanical producer will gasify 30 to 40 pounds of coal per square foot per hour.

Where only one producer is required, the mechanical producer also has the advantage of giving constantly a more uniform quality and temperature of gas. Where two or more producers are used and fired alternately the hand-stoked and hand-poked producer answers all requirements for quality of gas and, where only a few producers are required, is also cheaper to operate.

For ceramic kilns the gas producer should have the following special features:

1. It should operate without serious difficulty on any kind of coal.
2. The cost of the producer and the installation should not be excessive. The efficiency of a gas producer cannot always be judged by the price at which it is sold.
3. The cost of operation and for repairs should be light.

I have used mostly the rectangular producer, built up of brick, and have found it very satisfactory, when properly designed and constructed. To increase the capacity and give a more uniform gas I have recently equipped this producer with an automatic feeder and distributor. This leaves nothing to be desired in efficiency, except with a badly caking coal. I have not yet found it necessary to use a coal requiring an automatic stirrer to counteract the caking. The rectangular producer has decided advantages over the round producer and substantial brick walls give better insulation than steel casings, give no trouble from cracking and leaking, cost less and will last forever.

Temperatures from Producer Gas

Just how high a heat can be obtained in a compartment kiln with producer gas I cannot say. Knowing the composition of the gas and the temperature at which it is applied, the temperature of the air for combustion and the quantity of air used, the combustion temperature of the gas can be calculated. Lovejoy and Garve, in their paper on "Kiln Temperatures from Coal and Producer Gas,"¹ made elaborate calculations of temperatures obtainable from producer gas with Texas lignite. They found the combustion temperature of this gas at 500°C, 30% moisture, 25% air at 1000° and 20% radiation loss, to be 1382°, a little higher than cone 12. As I have put down cone 12 with producer gas from Dakota lignite, I know that their figure is not too high. How much higher I could have gone I do not know. At any rate the excess of air could have been less and much of the time the air for combustion would have been at a higher temperature than 1000°. Moreover, in such a kiln as I used, there would be no radiation loss in the combustion bags and the radiation loss from kiln would not affect the combustion temperature, but only the

¹ *Trans. Amer. Ceram. Soc.*, 12, 93 (1910).

amount of fuel required to make up this loss. In each compartment of this kiln there were 28 fires. That is one advantage of a gaseous fuel that a much larger quantity of fuel can be introduced and burned in the kiln. While this does not affect the combustion temperature, it does enable a kiln to be brought to the highest possible heat in all parts in the shortest possible time. Undoubtedly, under certain conditions, the temperature of combustion of the gas from a given fuel is increased by the steam blown into the producer to keep down the clinker, but on this point I have been unable to find any definite data.

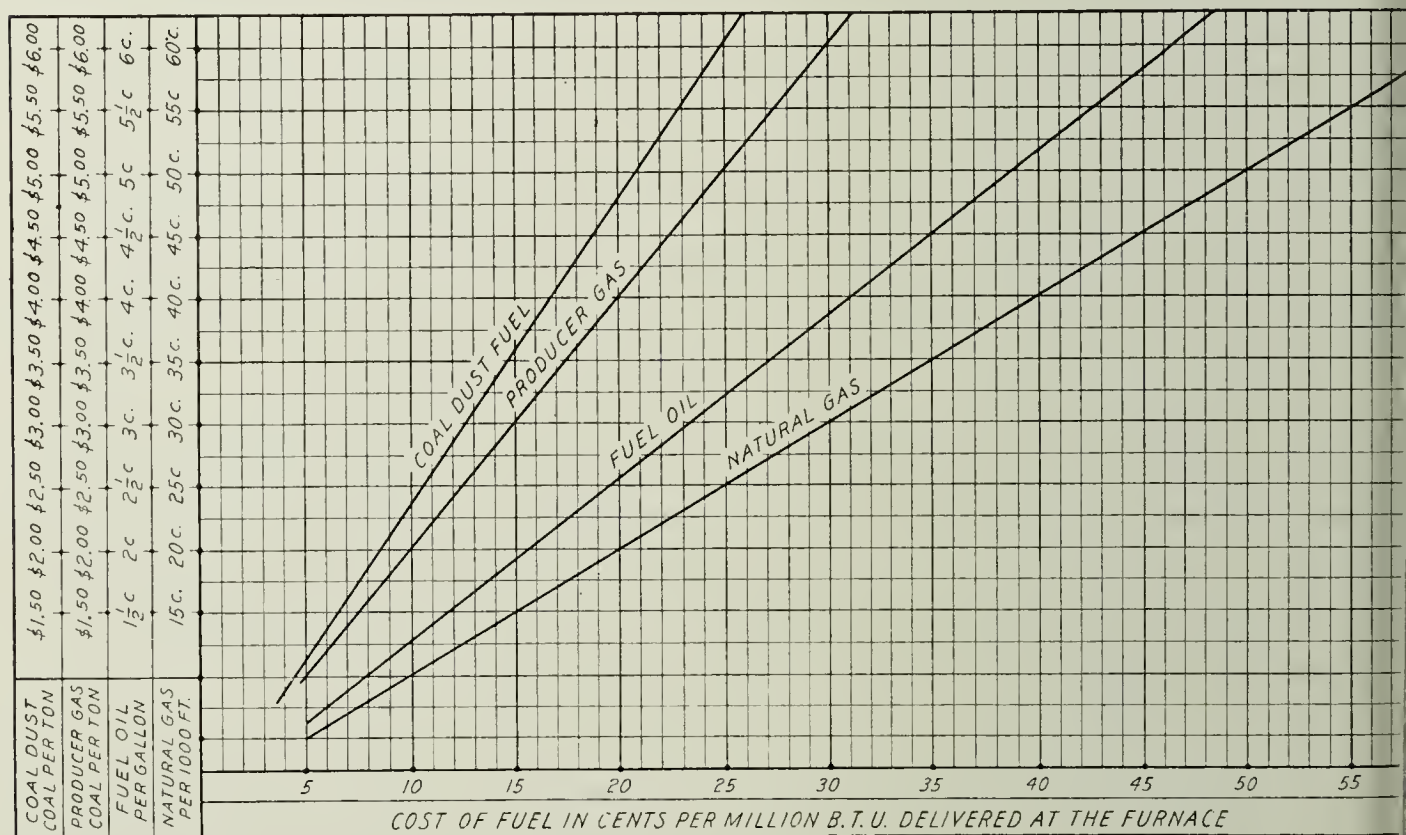


FIG. 1.

With recuperation, temperatures as high as 2200°C are possible. In the continuous kiln, temperatures up to 1400° are regularly obtained and 1500° is possible. Producer gas is used in burning German china, and such ware as Meissen and Dresden use a temperature of 1400° in glaze firing.

Economy of Producer Gas

Producer gas, in the continuous kiln, or with recuperative furnace is the cheapest fuel today in most sections of the country and coal is the only fuel we know of that can be permanently relied upon. In some sections, near oil fields or oil refineries and remote from coal mines, oil is the cheapest fuel. The comparative cost of the different gaseous fuels and of coal dust firing is shown graphically on the chart. As coal dust firing is impractical on ceramic kilns, this need not be considered.

As the most practical and economical way of obtaining high temperatures with producer gas is in the compartment kiln, the advantages of this kiln in systematic control make it worthy of investigation by every member of this SOCIETY.

Conclusion

By reason of the past failures of producer gas firing in fire brick plants in this country, and in view of my own successful experience with this fuel, and from my belief that it is the fuel of the future, I have felt it my duty to bring the subject up for discussion by our Refractories Division. I want also to bring to the attention of our Committee on Research and Development, the desirability of further investigations of producer gas and gas producers, with the purpose of securing additional information on the best methods of operating gas producers for the application of heat to the ceramic industries. Practically all work done in this line by the U. S. Bureau of Mines has been in the use of producer gas for power by direct combustion in engines. There is much yet to be learned in regard to the generation and application of producer gas for heat. Such investigations would be impractical for the individual. No doubt much has been done in this line that has not been published or is not available to most of us. Yet, there is too much guess work and too much variation in the opinions of operators on many important points.

Yet, notwithstanding all this, gas producer operation is today a practical success and no one who gives the matter intelligent investigation need make any costly experiments. Knowledge is available to those who seek it and when once interest is aroused it will not be long before the burning of refractories with producer gas is as common in this country as in Europe and probably more successful, since we generally improve upon European equipment when we undertake to adapt it to our conditions.

COLUMBUS, OHIO

COLD CLEAN ARTIFICIAL GAS AND A DISCUSSION UPON THE GENERAL PROPERTIES OF GASEOUS FUELS¹

BY ALFRED E. BLAKE

ABSTRACT

This paper² is written for the benefit of glass house people whose training has included no particular study of gas as a fuel. The advocacy of some departure from the common practice, in the light of good and sufficient reasons, ought to be met in a receptive attitude. Warnings are given as to the acceptance of non-standard processes, and apparatus proposed by those of precarious financial backing and questionable familiarity with the technicalities of gas supply and application.

There is a brief survey of the field to be covered, followed by a discussion which shows how various gases may be classified. There is a pronounced difference in quality between the various kinds of producer gas, and other standard gases. The heat content per unit volume of theoretically perfect air-gas mixture is shown to be approximately equal for all high grade gases. This value plus the reaction temperature form two important considerations in the comparison of gas fuels. The importance of high "thermal head" in relation to rapid heating, and the economies of rapid heat transfer are pointed out. The fitness of high grade gas fuel for attainment of highest efficiency is shown. Theoretical flue gas heat losses are given.

A standard of 1,000,000 B.t.u. is proposed as a conversational basis for approximate comparison of gases as regards cost and volumes required. The merits of regeneration or recuperation are obvious for large scale, high temperature heating, but there are many reasons for adopting direct fire heating units for small operations. This emphasizes the value of high grade clean gas. The use of muffles in leers when clean sulphur free gas is the fuel is ridiculous.

The cost of a method forms the general determining factor in selection when results to be gained are equal. Technical schools ought to give more training on the subjects of fuels and combustion. Apparatus, methods, materials, yields, properties, and application of coal gas, water gas, mixed coal and water gas, and coke producer gas to the glass industry are discussed briefly and illustrations are given. A table of comparison of these gases is given and is followed by the demonstration of the method obtaining the results given.

Introduction

In starting to prepare a paper on cold clean artificial gases for the use of those interested in glass manufacture, it seems best to "prepare the soil" so to speak, for the reception of ideas which may be new to some.

Mr. Floyd W. Parsons, in an editorial,³ makes the following statement:

Certain industries today continue to exist for no better reason than that they existed in the past. Certain practices continue to flourish although science has developed other methods to accomplish the same results more economically. Certain machines continue to be used in ever increasing numbers notwithstanding that other types have been perfected to do the same work at a lower cost.

¹ Presented before the Glass Division, Pittsburgh Meeting, February, 1923.

² This paper is destined for ultimate use as one of the chapters in a treatise on the Glass Industry, by Prof. Alexander Silverman, University of Pittsburgh, to be published by The Chemical Catalog Company, Inc. Its presentation here is by the courtesy of The Chemical Catalog Co.

³ *Gas Age Record*, Dec. 24, 1921.

It is not possible to determine what should be by simply observing what is. One important fault of humanity is its tendency to be skeptical of all things new, rather than all things old. We would be better off if we were more critical of today's methods and more sympathetic concerning tomorrow's possibilities. The greatest cost in industry right now is ignorance.

These words of Mr. Parsons seem very eloquent to any one who devotes his time to the betterment of the art of heat supply.

Natural gas and fuel oil will ultimately disappear as glass house fuels. How soon this will happen may as well be left to the judgment of those who must choose fuels. The chief controlling factor will be the cost. In spite of certain practical and certain economic objections to it, producer gas seems to be popular as a glass house fuel. The great and increasing diversity of glass ware, affords many instances, however, where use of the best gas obtainable is justified. Furthemorer, many conceivable cases can exist where high grade gas is preferable, due to local conditions. The aim in this article is to set forth enough information to enable one to form a fair opinion as to whether any consideration of high quality gas is warranted. Inasmuch as the requirements for fuel in an optical glass factory differ from those in a bottle works, and the requirements in an art glass factory differ from those where oven ware or chemical ware is made, it is hoped that these views will not seem far-fetched to any who do not happen to be in touch with every phase of glass making.

The glass industry has been so favored in the past by cheap fuel of the highest quality, and portions of it are still so favored, that it is certain that a great percentage of glass men have never had any occasion until recently to give heed to the problems of fuel supply, and as evidence of this, very many costly mistakes have been made in trying to substitute one fuel for another.

It may take time to look into a fuel problem from all angles and to weigh all the arguments which are presented; but it is infinitely better to do so than to invite expensive failures by making snap decisions, not based upon sound technical facts. Oft times one can save much mental effort if he will simply consider the source of the information being given.

It is always safe to assume that those who are specialists in the gas industry are eager to secure any new process which has merit, and they are generally the first to learn of new developments or to develop new processes themselves. Many processes being offered industrial concerns today have already been very emphatically rejected by the leading gas engineering concerns.

Very likely a majority of glass manufacturers in natural gas territories hold the idea that producer gas is the only other gas besides natural gas; forgetting completely that whole towns, cities, and counties are being supplied with gas which is as suited in every way for glass making as

natural gas. The cost for city purposes is usually high, compared to natural gas prices, but such regions are generally long distances from coal and coke sources, and the distribution cost to domestic consumers is very considerable.

The number of gases to be considered is really quite small, and there are certain means for classification of gases as to fuel value which simplify matters still further. I propose to deal only with the ones which can be made by use of standard equipment and which involve no experimentation whatever. Any others which the reader may care to consider, as they may come up in the future, can be easily judged as to merit from the cases to be given.

Generalities in Technology of Gaseous Fuels

It is common to speak of the heat content of a gas and refer to the number of British thermal units per cubic foot which it contains, as though that were the final criterion for judging gas. It is not. In combustion, the air that is consumed is exactly as important as the gas. Water, electricity, steam, etc., are used as delivered; but gas must be supplied with air, or it is of no value as a source of heat supply. Owing to the different gaseous chemical substances composing various gas fuels, some take greatly different amounts of air than others.

Suppose we have 1 cubic foot of 1100 B.t.u. natural gas, which requires ten times its volume of air to insure complete combustion. We have:

	1 cu. ft. natural gas plus
	10 cu. ft. air
Total	11 cu. ft. theoretical mixture

11 cubic feet of this mixture contains 1100 B.t.u. $\frac{1100}{11} = 100$; or each

cu. ft. of mixture will liberate 100 B.t.u. when combustion takes place.

Now consider blue water gas with a heating value, so called, of 300 B.t.u. per cubic foot. Each cubic foot of gas in this case requires 2 cubic feet of air

equaling 3 cu. ft. of mixture, which carries 300 B.t.u. $\frac{300}{3} = 100$, or each

cubic foot of mixture will liberate 100 B.t.u., as in the case of natural gas.

The air requirements in these two cases are stated approximately and for illustrative purposes. To carry the case out for producer gas, we have let us say, a 150 B.t.u. gas, and 1 cu. ft. requires 1.7 cubic feet of air for complete combustion. The mixture which would have 150 B.t.u. would

be 1.7 + 1 or 2.7 cubic feet. $\frac{150}{2.7} = 56$, or a cubic foot of mixture has 56

B.t.u.

If other factors were equal, one would surmise that the matter of equal heat delivery resolves itself into getting the heat units into the field of action at the same rate in any case. This would mean that $\frac{1100}{300}$ or $3\frac{2}{3}$ times as great a volume of blue water gas would have to be burned in place of one volume of natural gas or that $\frac{1100}{150}$ or $7\frac{1}{3}$ times as much producer gas would have to be used in place of natural gas. This would hold except for the fact that gases do not all burn with equal speed or intensity. This is due to their varying makeup. Practically all of the natural gas from eastern fields is 100% combustible. Blue gas is about 91% combustible; but its combustible components, hydrogen and carbon monoxide, burn with great speed, whereas natural gas, being chiefly methane, CH_4 , is quite slow burning. Methane must undergo decomposition before its carbon and hydrogen can oxidize, and the decomposition requires both time and some of the heat which would otherwise be available. Coal gas and by-product coke oven gas, with their large percentages of hydrogen, each burn faster than natural gas.

Combining the foregoing with the statements in the preceding paragraph as to air requirements, another angle to the subject suggests itself. Whether the fuel is natural gas or blue water gas, it seems that the volume of air plus the volume of gas necessary to supply 100 B.t.u. is a constant quantity, namely 1 cubic foot. Therefore, while in one case we are using three times the volume of gas as in the other, it turns out not to be a fact of the slightest importance so far as delivering heat in proper concentrated form to the furnace goes. As to producer gas, however, we have a case comparable to such an instance as the following: One solution of sulphuric acid and water is 25% acid by weight. Another solution is 50% acid by weight. The amount of each solution is such that the same weight of acid is contained in each. Naturally, the 50% solution has less water and may be expected to dissolve a batch of metal more rapidly than the 25% solution. In this case, the excess water is comparable to the high percentage of non-combustible nitrogen and carbon dioxide always to be found in producer gas. From the statements already given, the ratio of concentration of heat units from the use of natural gas or blue gas to the concentration of heat units from use of bituminous producer gas is about 100:56.

It is evident, therefore, that 1000 B.t.u. of natural gas, or of blue water gas or of producer gas are not equal in heating value. We find by definition that a B.t.u. is that quantity of heat which will increase the temperature of one pound of water 1°F . The establishment of such a heat unit does not enable us to compare the merits of gases directly. If heat

must be transferred at the temperature of 2700°F it is very important to be sure that the gas to be used will enable that temperature to be maintained *without undue waste*.

A water fall is a source of mechanical energy. The higher the fall, the greater the "head of water" obtainable in harnessing it for service, consequently the greater the available energy. Fuel engineers have coined the term, "Thermal head." The analogy is obvious. One of the laws of thermodynamics states that the greater the difference in temperature between two bodies placed in contact, the more rapidly will the coolest of the two absorb heat from the other. "Thermal head" simply means a difference in temperature. When heating glass with gas, the heat transfer is from gaseous products of combustion to solid or liquid. The hotter the products of combustion, the faster the heating.

Some gases when burning, liberate products of combustion at much higher temperatures than others do. This is one of the chief reasons why one gas fuel is better than another. In order to have a basis for comparing gases in this very important respect, one may calculate the temperature which would be reached by the products of combustion if all the heat liberated in reaction were applied to heating these products only. The calculation is a difficult and tedious one and the result is purely theoretical. It is commonly spoken of as "theoretical flame temperature," although it is more proper to refer to it as the "theoretical reaction (or combustion) temperature." This temperature, correctly calculated, is a very important item among the properties of gas fuels commonly mentioned. By use of it, we can judge the "thermal head" to be expected by use of a gas. Even when a quantitative or perfect theoretical mixture of gas and air is burned, the theoretical reaction temperature is not attained, owing to heat losses by radiation of light wave energy, and partial dissociation of some of the gases involved.

It happens to be a fact that these theoretical reaction temperatures for the high grade gases run very close together. They vary with the composition of each particular gas; but in general, natural gas yields the value of about 3370°F ; blue water gas 3470°F ; coal gas 3300°F to 3450°F ; by-product oven gas 3300° to 3400°F . For practical purposes I consider them all as being equal.

The case of producer gas is different from the others, however. Depending upon its composition, such gas will range in reaction temperature from 2400°F to 2900°F . The reader will be able to understand why the French term for producer gas means "poor gas." (*Gas pauvre*.)

We are in position now to answer the question about the relative value of heat units from one source or another. Suppose we wish to maintain a furnace interior and its contents at the temperature of 2500°F using producer gas which can yield, theoretically at least, combustion product

at 2800°F. The amount of heat which with the combustion gases, and inert gases, can yield to the furnace and batch is that which is necessary to give them the temperature of 2800°F minus that which is necessary to give them the temperature of 2500°F, or the amount required to make a difference of 300°F. Therefore, the thermal head is 300°F. The rate of heat transfer will have a certain definite value.

Suppose instead of producer gas we use a gas having a reaction temperature of 3450°F. Then the thermal head will be 3450–2500 or 950°F, and the rate of heat transfer will be proportionately higher than in the case first given. The work to be heated will *be able to absorb a higher percentage of the heat liberated*; in other words, higher thermal efficiency will be secured from 1,000,000 B.t.u. of natural gas than from the same number of heat units supplied as producer gas.

When the heat transfer is rapid, less heat has a chance to be carried into the flue, or through the roof or walls of the furnace.¹ To make this a little clearer we may say that good furnace practice is such that the temperature at the flue hole in a furnace is about 200°F higher than the temperature of the material being heated. In each case given above, therefore, the thermal head, or effective drop, is 100°F and 750°F, respectively.²

We must emphasize the fact that we are not concerned merely with the quantity of heat units we have to deal with, but we are interested also in knowing what the form is; whether as a gas which enables one to secure a good thermal head, or rapid heat transfer; or as gas which will not even approach the furnace temperature required.

If either of two gases can be used to do a given piece of work, then the problem may be chiefly financial, since cheapness may often overrule thermal efficiency. Few glass concerns have means for knowing surely what the comparative possibilities of two gases may be when applied to a particular piece of work. Here is another instance where the cost of expert advice may be well justified.

Fig. 1 is a plot which shows conveniently just what the flue heat loss is for each of several gases, when their products of combustion leave at a stated temperature. The data has been made up by assuming the use of the theoretical amounts of air for complete combustion for each gas, and determining the weight of each constituent of the flue gas, per unit of fuel, for use with the various specific heats in determining the sensible heat for

¹ Unless expressly stated otherwise, these cases which are cited relate to direct firing only.

² Furnace practice and furnace design are so important as factors that it is difficult to write the present discussion without more mention of furnaces. In the two cases given here, it is assumed that the reader will realize that merely to produce such a parallel, furnaces of different design would be necessary. As a matter of fact, the cold producer gas could hardly be used with air for securing the temperature of 2500°F, and it is never to be recommended for *efficient* work above 1700° or 1800°F.

various temperatures. In other words, the figure shows at a glance what percentage of heat generated is carried away by the flue to waste for any given flue gas temperature.

From the foregoing, one can see that to simplify our expressions with regard to various gases of different thermal qualities, we should make some kind of generalization to be used in ordinary discussion. This can be done very conveniently. Most glass house men have been accustomed to think in terms of natural gas, and in thousands of cubic feet of it. The price per thousand is a figure easily retained for comparative purposes. Natural gas after thorough stripping for motor fuel, etc., contains about 1000 B.t.u. per cu. ft. Therefore, 1000 cu. ft. contains 1,000,000 B.t.u. Then

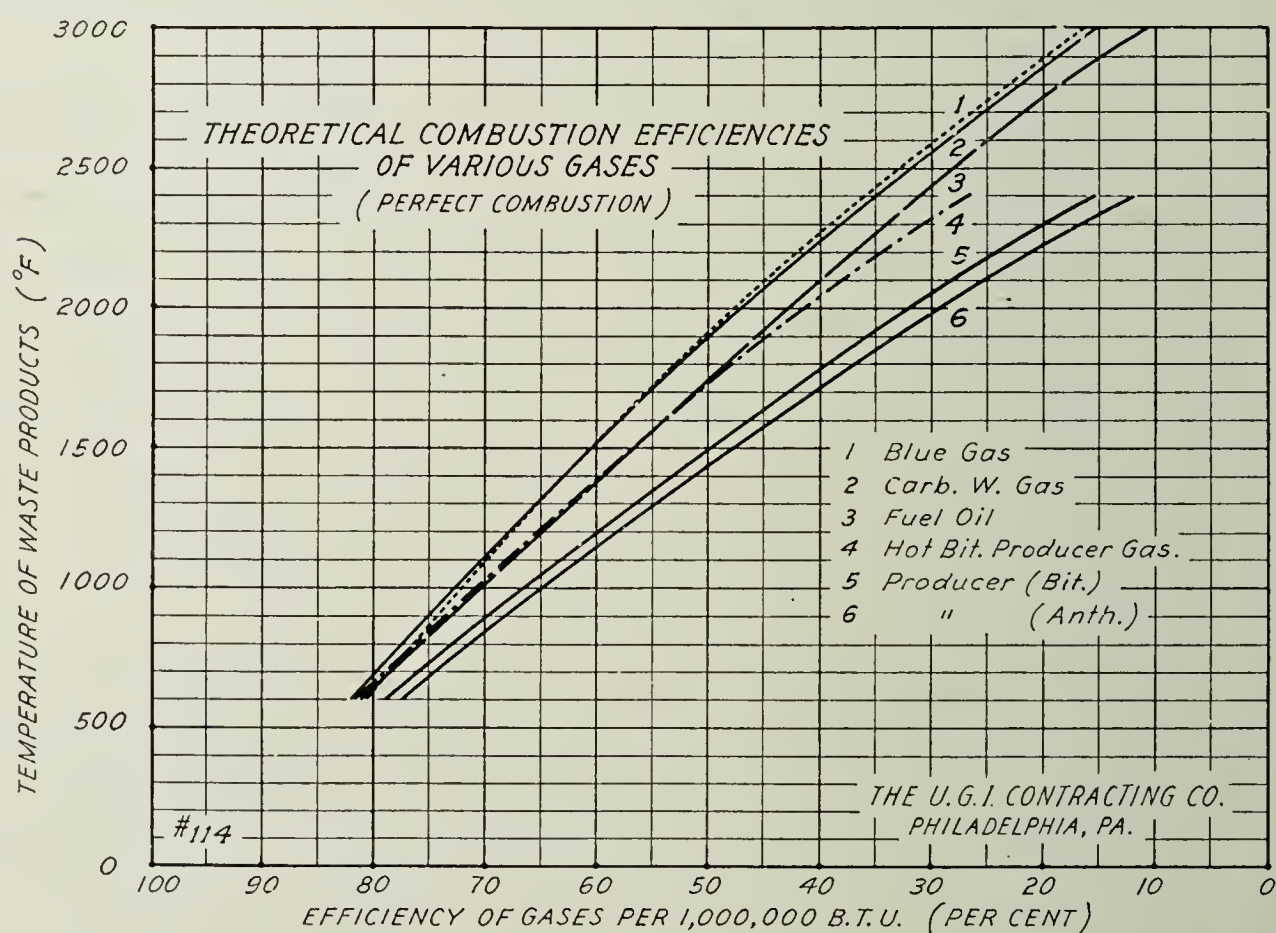


FIG. 1.

the price of 1000 cu. ft. is the same as the price for 1,000,000 B.t.u. It is also fortunate that natural gas is one of those which has a high theoretical reaction temperature; so that all things considered, it forms a fairly satisfactory standard of heating value for high grade gas fuels.

To duplicate the heating effect of any given amount of natural gas by the use of some other *high grade* gas, we have seen that it is necessary to furnish the latter in volume sufficient to carry the required heat units. Little else matters, if the combustion is to be controlled by modern equipment. In any discussion about costs, it is a very simple matter, therefore, to speak in terms of thousands of cubic feet of natural gas, or better, in terms of millions of B.t.u. When this is done, confusion is eliminated,

and direct practical comparisons can be made as closely as the present state of the art of heating on a large commercial scale warrants their being made.

The foregoing considerations have been based upon direct firing practice, that is, by use of cold air and cold gas, with no preheating. In large furnaces, where high temperatures are required, direct firing is so wasteful that none but the most benighted are continuing the practice. With cold producer gas, high temperatures simply cannot be secured by direct firing, as stated before. If any method of preheating will make a useless gas useful, so much the greater reason for preheating when high grade gas is used.

There are many heating operations required in various instances of glass making which call for numbers of small furnaces, and for furnaces which have never yet been designed for any other fuel than gas. The temperature required may be high, as in sealing, softening, polishing, cutting, etc., or low, as for annealing; but whether one or the other, the size of furnaces must be kept as small as possible to save factory space. High quality gas is justified here even at a cost greatly in excess of any substitute. High quality gas will give the temperature desired without recourse to preheating. It is handled with great ease, with the smallest possible sizes of pipe, and the control of firing can be automatic and perfect. It can be supplied perfectly clean and free from sulphur, tar, dust, and other matter which might be injurious to quality.

Another consideration favoring clean high grade gas is that found in the elimination of muffles or semi-muffles. Good firing practice has proven these to be entirely unnecessary for the protection of the ware when clean gas free from sulphur is used, as all glass men know who have used natural gas. High grade gas can easily compete with "cheap," (?) dirty gas by the elimination of muffles. This is because of the necessity for using vastly more heat in a muffle furnace in order to secure the desired temperature in the ware. The interposition of the muffle between combustion zone and ware cuts off contact between the ware and combustion products which carry the heat. Instead, the heat must pass through the muffle wall, which generally consists of clay or material containing carborundum, in order to heat air which will pass the heat finally to the ware. Far greater thermal heads are necessary in muffle heating. This is in spite of the very clever and attractive appearing muffles which are offered.

The fact must be recognized that ways can be found for making an excellent product with the poorest fuels. If these methods will stand the economic tests, meeting competition, and prove to be the most profitable to the investors, little remains to be said for the use of different methods and materials. It will behoove every management to spare no pains in these days, however, to investigate the offerings of *going concerns* who have *standard equipment* which can be adapted for glass house use.

It is regrettable that technical institutions which aim to train men for glass house and ceramic engineering are generally so backward in the matter of giving adequate instruction in the technology of fuels and combustion, and that such matters are generally handled through the departments of Mechanical Engineering as though they had no relation to chemical practice.

Standard Gases

A. Coal Gas (Also By-Product Coke Oven Gas).—Coal gas is evolved in the destructive distillation of bituminous coal. Ovens of various sizes and shapes, built of clay, or preferably of silica ware, are employed. These in general have one long dimension, which may be horizontal or vertical. Appropriate means are employed for heating the retorts continuously, and coal is generally charged in batches, intermittently. The heating may be accomplished by the use of part of the coal gas made; or producer gas, preferably made from coke screenings, can be used. Recuperation or regeneration of heat should be practiced by preheating the air used for combustion. High volatile coals are preferable. Twenty-nine per cent to 38% volatile combustible matter represents the usual limits. Depending upon the numerous factors involved, the total gas yield is from 9000 to 13,000 cubic feet per net ton. The calorific value of coal gas can vary with conditions between 450 and 650 B.t.u. per cubic foot. A fair figure for the yield of heat units as gas per ton of coal would be 6,400,000 B.t.u. If coal gas is used to heat the ovens, about 40% of the total make is required, and all of the small coke (breeze), with additional fuel, will be required for boiler fuel in supplying the steam necessary to operate the various plant accessories. If the small coke is used to make producer gas, all of the coal gas can be sent out, and waste heat boilers can be interposed at suitable points to recover heat and furnish all the steam needed.

In addition to gas, coke, tar, light oils, ammonia, and other residuals are made in sufficient quantities that their total market value should exceed the operating cost by at least a small margin. It would interest glass melters to know that the tar is at least as valuable as oil for fuel. Good average practice with vertical retorts will show a yield of from 12 to 14 gallons of tar which is very fluid and a suitable oil substitute. By such use, nearly 2,000,000 more heat units can be had per ton of coal.

Coal tar is removed from gas with ease; so that the gas can be completely purified, if desired. Two constituents of coal gas which are objectionable for glass finishing work are hydrogen sulphide and carbon disulphide. These have no influence in melting except to furnish additional heat. The first named may be present in quantity up to 800 grains per 1000 cubic feet; 600 grains would be common. It is possible, however, to remove it to leave the merest trace, or 2 grains per 100 cubic feet. Carbon

disulphide occurs in smaller quantities (10–50) grains per 100 cubic feet, but it is much harder to remove. A very efficient process for doing this exists, however.

Following is a typical analysis for coal gas (*a*) and one for by-product coke oven gas (*b*).

<i>(a)</i>		<i>(b)</i>	
Carbon dioxide (CO ₂)	2.6	Carbon dioxide (CO ₂)	2.1
Illuminants	3.2	Illuminants	2.0
Oxygen (O ₂)	0.2	Oxygen (O ₂)	0.3
Carbon monoxide (CO)	6.4	Carbon monoxide	6.0
Hydrogen (H ₂)	46.8	Hydrogen (H ₂)	57.0
Methane (CH ₄)	35.4	Methane (CH ₄)	27.0
Nitrogen (N ₂)	5.4	Nitrogen (N ₂)	5.6
B.t.u. per cu. ft.	605	B.t.u. per cu. ft.	528
Specific gravity	.42	Specific gravity	.38
Theoretical reaction temperature	3407°F	Theoretical reaction temperature	3407°F

The foregoing remarks have been made general enough, purposely, so that they will serve to cover by-product coke oven gas. The latter generally does not have as high a calorific value as coal gas, but otherwise no important differences exist. By-product coke ovens do not yield as great a return in gas heat units, or in tar and ammonia as vertical retorts, and they have their greatest field in the production of metallurgical coke. They are very costly when considered only for small requirements.

Coal gas and by-product oven gas have been used for years for glass making and finishing. The writer knows of no instance in the past, however, in which the gas was not purchased by the glass people. Except as an adjunct to a complete gasification plant, a coal gas plant would be too costly and complicated an investment for a glass concern. Probably the hardest problem would be in the regular and profitable disposal of coke. Under another heading, coke disposal will be discussed further.

The accompanying illustration shows, in section, a modern retort plant, including retorts, housing, foundations, coal and coke handling equipment, producer house, with breeze producer, bin, blower, gas main, cyclone dust

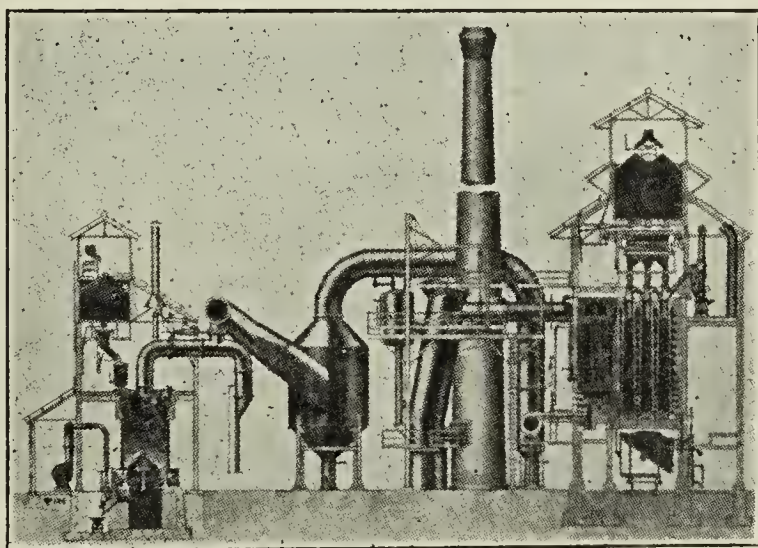


FIG. 2.—The U. G. I. intermittent vertical retort system with detached producer and waste heat boiler. The U. G. I. Contracting Company.

arrester, dust legs, and method of recuperation; also waste heat boiler, drum, stack, etc.

The retorts are built in benches of nine. Seven benches constitute a battery. One producer will serve each battery. When a plant having less than seven benches is required, the producers are built in conjunction with the retorts. Normal duty for each retort is the carbonization of 2.2 net tons of coal per 24 hours. All steam requirements, for producers, blowers, exhausters, fans, etc. are met by the boiler.

Water Gas.—Two kinds of water gas are standard. The term water gas is usually taken to imply carburetted water gas. Carburetted water gas is made by cracking oil in an atmosphere of blue water gas. The oil vapors serve to enrich the blue gas by the addition of hydrocarbons, especially those which cause flame luminosity. 2.65 gallons of oil per thousand cubic feet of finished gas will give a product having about 550 B.t.u. per cubic foot. The gas is used chiefly for domestic and commercial purposes, but it is used industrially also, when the application is such that the usual high cost is overbalanced by higher efficiency, increased production, and higher quality of production.

Carburetted water gas is as well suited for glass house use as coal gas or natural gas, and there have been many applications. No glass concern would be warranted in owning a carburetted water gas plant, in the writer's opinion. The future for oil is too uncertain, and it is an unnecessary material, as may be seen.

Blue water gas, so called because of its blue flame, which is due to the large content of carbon monoxide, also known as straight water gas, or uncarburetted water gas, is made by the intermittent action of steam upon incandescent carbon, which is heated once each cycle of operations by blasting with air. A typical cycle would have a blasting period of one minute, an upward steaming or "run" of one minute and a downward steaming of one minute. The coke, or anthracite coal, is held upon a grate in a brick-lined insulated generator, suitably connected with air, steam, gas piping, valves, etc. The best practice includes automatic control apparatus for operating the valves and ensures results which are uniform, with a minimum of supervision. All but the smallest blue gas generators should be provided with waste heat boilers, with which all steam required can be made from the heat in the blast gases and the water gas. The generators are built in sizes which have standard ratings from 2,000,000 B.t.u. to 26,000,000 B.t.u. per hour, as blue gas, or from 4 feet to 12 feet outside diameter.

The accompanying illustrations show a small blue gas generator, with accessories, in section, with grate, coke charge, valves, seals, piping, stack, etc. in view; also a larger set, showing in addition to the features mentioned, automatic control, waste heat boiler, etc.

The object in blasting with air is the production of heat in the charge by the action of oxygen upon a portion of the carbon. Blasting is conducted at high pressure and the greater the CO_2 content of the blast gases (really lean producer gas) the greater the heat liberated in the charge per pound of carbon gasified. In general, the blast gases may have only

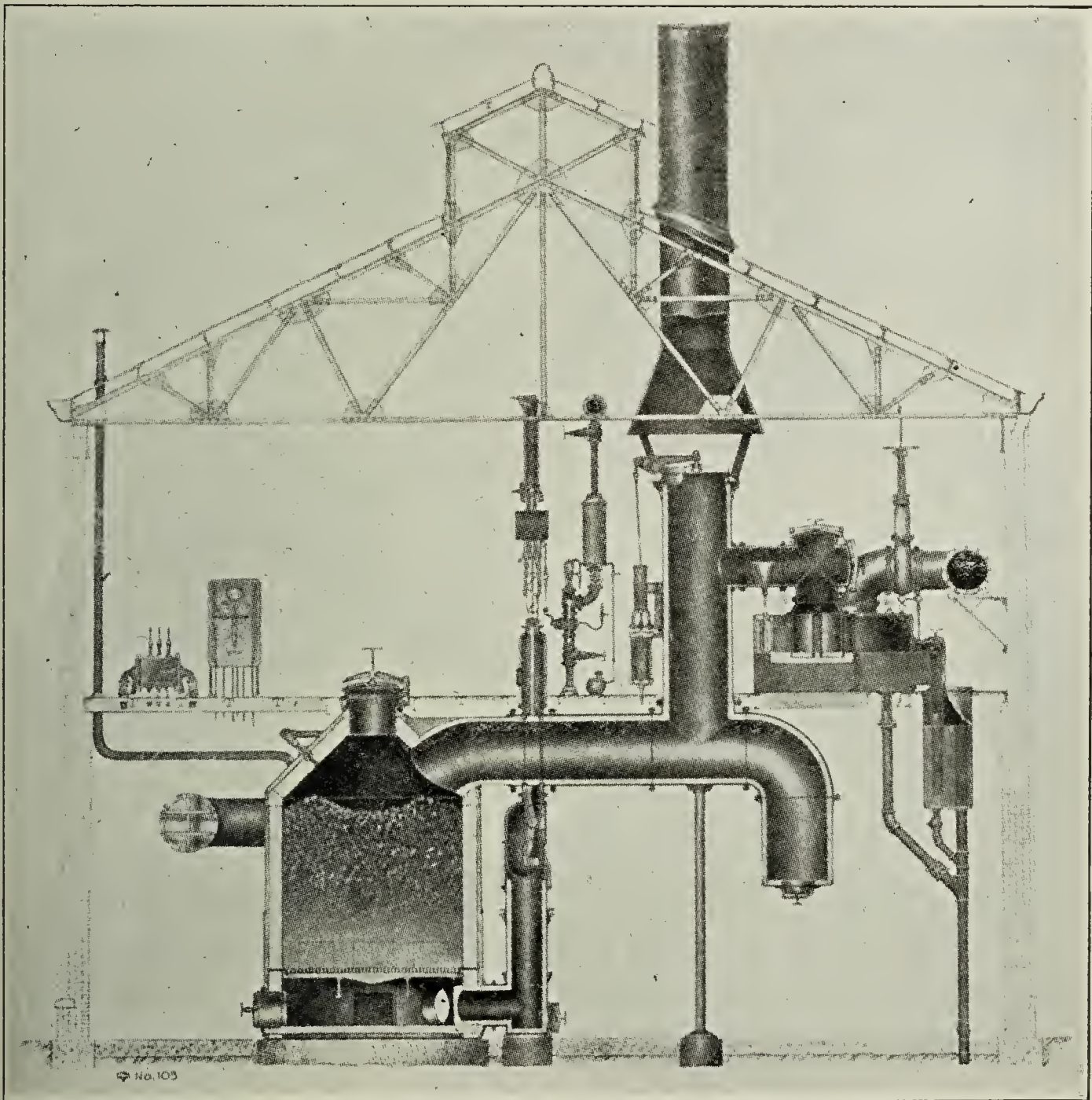
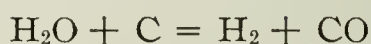


FIG. 3.—The U. G. I. blue gas apparatus (cross-section). The U. G. I. Contracting Company

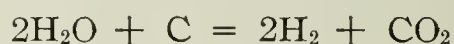
about 10% CO . High pressure blasting enables the length of blasting period to be shortened to a minimum.

It is necessary for the charge to be well and uniformly heated when steam is to be applied, to such an extent that a maximum steaming period can be secured. The reaction of steam upon hot carbon is endothermic, that is, it requires an external heat supply and a working temperature above a certain minimum, or the desired results will not be forthcoming.

The desired result of steaming is shown by this chemical reaction:



If the temperature of the charge becomes too low, however, the reaction becomes:



which is undesirable. It can be seen that the process is simply a cycle designed to take the best advantage of the thermo-chemical behavior of

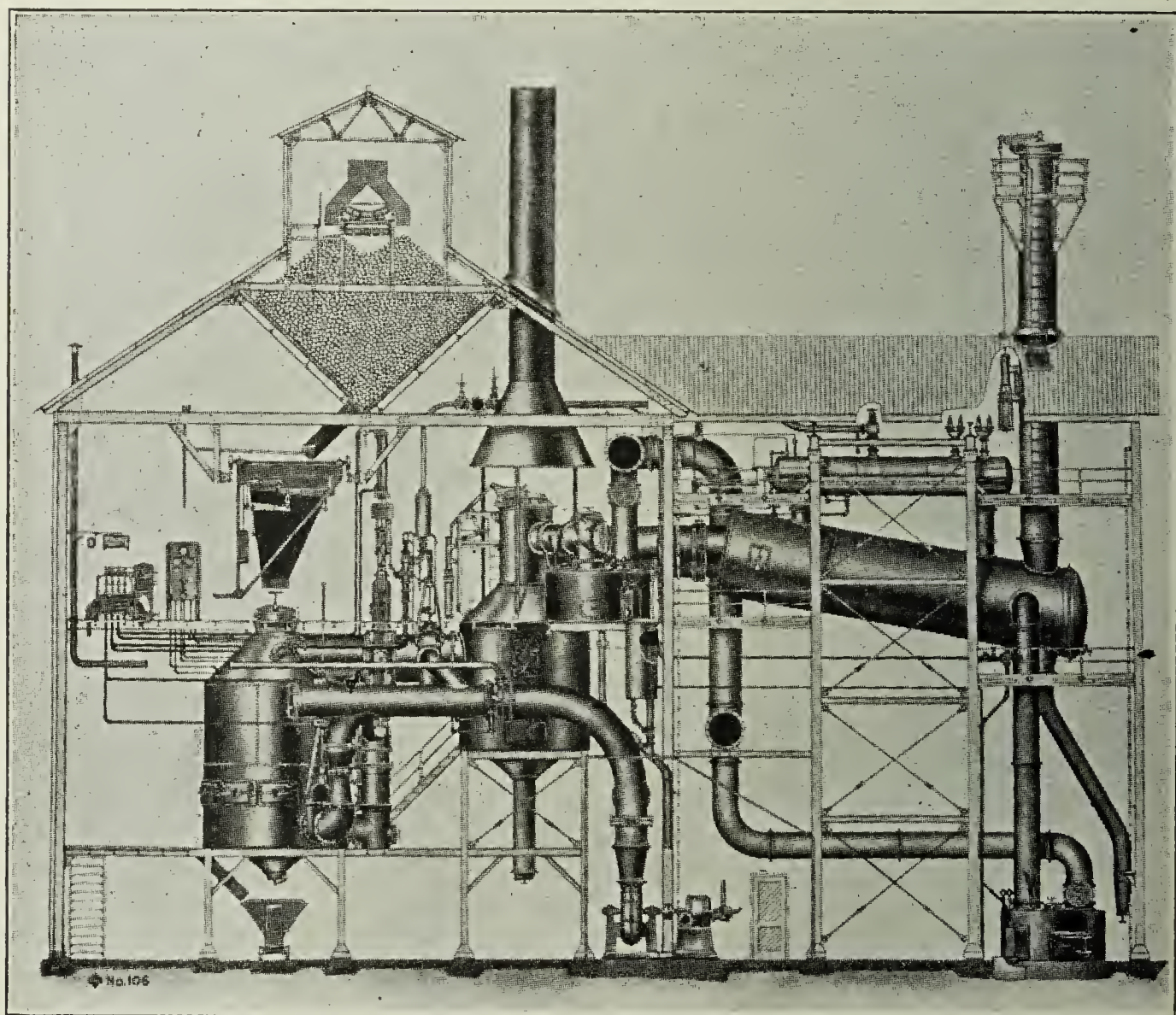


FIG. 4.—The U. G. I. blue gas apparatus with waste heat boiler. The U. G. I. Contracting Company.

steam and carbon. With automatic valve operation, accurately timed, and the use of waste heat boilers, the thermal efficiency of the process will be from 65 to 70%, or equal to very many producer gas operations, with the added advantage of vastly superior quality of gas resulting.

Blue gas, like producer gas, is poisonous, because of its carbon monoxide content, but as a warning against leakage, it is a very simple and inexpensive matter to give it an odor by means of which it can be detected promptly. Phenyl-isocyanide, one of the stench of chemical warfare has been used with satisfaction.

Any number of generators can be installed in a plant in order to have the desired capacity and operating features. Spare sets should be included, whenever continuous operation is desired, since a generator grate should be cleared of ash and cinder about once in eight hours. Large generators can be built in pairs, to use a common waste heat boiler. In order to insure a steady gas supply, a holder must be used as a temporary storage space for gas. Its size will depend upon operating conditions.

Following are analyses of carburetted water gas and blue gas.

CARBURETTED WATER GAS		BLUE GAS	
Illuminants	10.7%	Carbon monoxide (CO)	43.5%
Carbon monoxide (CO)	33.4	Hydrogen (H ₂)	47.3
Hydrogen (H ₂)	38.1	Methane (CH ₄)	0.7
Methane (CH ₄)	7.6	Carbon dioxide (CO ₂)	3.5
Ethane (C ₂ H ₆)	2.4	Oxygen (O ₂)	0.6
Carbon dioxide (CO ₂)	3.3	Nitrogen (N ₂)	4.4
Oxygen (O ₂)	0.7		<hr/>
Nitrogen (N ₂)	3.8		100.0%
	<hr/>	Specific gravity	0.559
	100.0%	Calorific value	302 B.t.u.
Specific gravity	0.676	Reaction temperature (calc.)	3470°F
Calorific value	602 B.t.u.	Specific heat	.45

Blue gas has been demonstrated as superior to carburetted water gas, coal gas, and mixtures of these, for many manufacturing purposes. This is especially true in the incandescent lamp industry where highly developed apparatus for cutting and sealing is used. It is an ideal gas when purified, for annealing, polishing, heating glory holes, decorating ovens, and enameling.

The cost of blue gas when high grade equipment is used, depends chiefly upon the cost of coke, or anthracite coal, but also upon the requirements of the factory which is to be served. For instance, a 24-hour demand will enable a much cheaper production than 8- or 10-hour demands. Except for *small installations*, or in cases where the glass factory can obtain a supply of cheap coke or anthracite, blue gas plants by themselves are not likely to become frequent in the glass industry. Where the value of a glass product is high, and no great quantities of gas are called for, but a high temperature is essential, as in cutting, sealing, decorating, polishing, and the like, the use of blue gas should have careful consideration. When the proper modifications to blue gas apparatus have been perfected to permit the substitution of bituminous coal for coke, the use of blue gas in glass manufacture will immediately command the attention of all glass makers. A development of this sort can be looked upon as the next logical step in the design of industrial gas apparatus. Many interesting attempts have already been made along this line. For years past, much carefully worded printed matter has been available, gotten up to show how simply

the problem can be solved, and promoters with little financial standing have been ready to promise whatever might be satisfactory to the prospect.

Complete Gasification of Bituminous Coal to High Grade Gas

We know that the coke from a coal gas plant can be gasified with ease, either to make blue water gas or clean producer gas. Each process is a standard one which has been used for many years. Making coal gas and purifying it involves no difficulty whatever. The same is true for blue gas and coke producer gas. Complete *two-stage* gasification consists simply in building a coal gas plant and a blue gas plant side by side, or in certain cases, the work to be handled might enable the substitution of coke producers for blue gas sets. The coal gas plant would supply coke for blue gas or producer gas. The 600 B.t.u. coal gas would be mixed in the same holder with the 300 B.t.u. blue gas to yield gas of about 375 to 400 B.t.u. per cu. ft., the calorific value depending upon the coal used. If the coke is used for making producer gas instead of blue gas, it would be poor practice to mix the two, because too large a holder would be necessary for proper mixing, and because such a producer gas section can be made so automatic in its operation as to require no holder whatever. This would permit of using coal gas and tar for heavy melting operations and producer gas for annealing and other comparatively low temperature work. The producer gas from coke can be made cool and clean, hot and

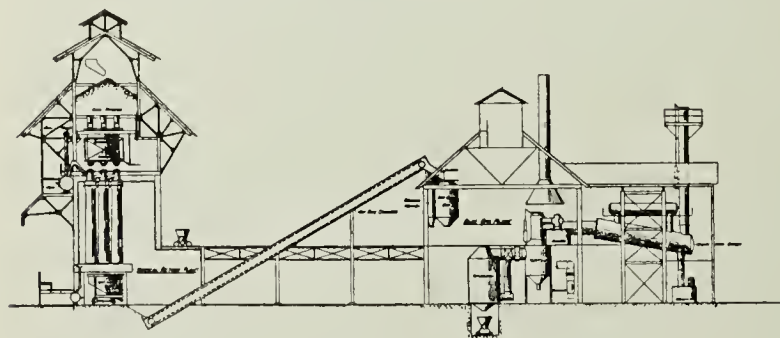


FIG. 5.—U. G. I. combined coal and blue gas plant.

clean, or hot and containing dust. The selection would depend upon requirements and upon the nearness of the gas plant to the factory. One ton of coke would yield about 150,000 cu. ft. of 128 B.t.u. gas. The cut which illustrates the section of a coal gas plant shows the type of producer in mind,

with cyclone dust arrester and fittings for making hot clean gas (1020°F) for heating coal gas benches.

The following illustration is a sketch outlining a complete gasification plant, in which is shown the retort plant (which is integral with the producers in this case), conveyor for hot coke, hot coke screen, insulated bins for the lump and fine coke, lorry car for supplying the producer with fine coke, blue water gas section, etc.

Nothing novel is involved at any stage of the complete gasification process illustrated above. Every operation is one which has been standard practice for many years.

The total cost of gas made by this two stage process, including investment charges enables very close competition with natural gas in such localities as Western Pennsylvania and Ohio, where good low cost coal is available, and the cost for natural gas is being advanced. With coal delivered at \$3.00 per net ton, a fair sized plant will make mixed gas at costs ranging from \$.35 to \$.40 per million B.t.u. depending upon size of plant, quality of coal, factory demand characteristics and other conditions.

Other Gases

1. Clean Producer Gas from Bituminous Coal.—Numerous interesting attempts have been made to clean bituminous producer gas, some of which have had a measure of success. Not only is such gas exceedingly difficult to make entirely free from tar, but the tar which is recovered amounts to from ten to sixteen gallons per ton, and is invariably so impregnated with water, ash and carbon, and is so viscous, as to be not only worthless, but it constitutes a liability, in that it is most difficult to dispose of. No satisfactory solution has come to the writer's notice thus far. The cleaning processes used do not remove sulphur compounds; so that furnace provisions must be in accord with that fact. A muffle leer heated with cold producer gas would be about as inefficient a piece of combustion engineering as one can imagine. The loss of combustible material as tar amounts to from 1,500,000 to 2,200,000 B.t.u. per ton of coal gasified; an additional source of inefficiency as regards the adoption of this sort of producer gas.

2. Coke Producer Gas (Also Anthracite Producer Gas).—Coke makes excellent producer gas, which *carries no tar* and which, therefore, is easily cleaned. A good sample of such gas would have about 128 B.t.u., contain about $12\frac{1}{2}\%$ hydrogen and 27% carbon monoxide. Its theoretical air-gas mixture would contain about 65 B.t.u. per cubic foot.

In addition to the high pressure type of coke producer shown in Fig. 2 are numerous makes of suction producers ranging in capacity from 300,000 B.t.u. in gas, to 9,000,000 B.t.u. per hour. Their capacity for unit grate area is very low, but they are of some utility where demand is low and variable. One general application for them is in the operation of gas engines for power purposes. The gas can be conveniently purified, however, for use in low temperature work. Whenever small coke or anthracite screenings can be had at low cost, it may be found profitable to look into the possibilities for its application in certain glass work, where the demand for gas is very small indeed.

3. Producer gas can be made from oil, which, in appropriate apparatus, will yield gas of heating values from 400 to 600 B.t.u., and with reaction temperatures as high as that of natural gas. It is necessary to use oils which are *non-coking*, however, and these are not only difficult to secure

in dependable supply, but their cost makes the use of the process prohibitive for any but the most special cases and localities where coal and coke are dear, and oil is cheap, as in the far west.

General

No gases not mentioned in the foregoing are standard as yet for industrial fuel uses. Doubtless new processes will be developed which will have great merit. In entertaining the use of any sort of artificial gas, however, whether it is standard or not, money, time, annoyance, and disappointment can be avoided if the management will seek the advice and services of concerns which are obviously competent in the field of gas and combustion engineering. For double protection, every progressive concern, bent upon eliminating mistakes and waste, should employ at least one man who is trained and experienced in the company's fuel problems in whom they can place confidence, and who can translate to them the merits of every proposal for the solution of fuel problems.

As the glass industry is still emerging from craft to a scientific basis, many opinions upon fuel and furnace practice are founded on what is akin to superstition, derived from the old rule of thumb methods and imported to this country with our various branches of industry before any transition had begun. If the facts and ideas given here are stated clearly enough to demonstrate how reasonable they are, the writer's object is accomplished.

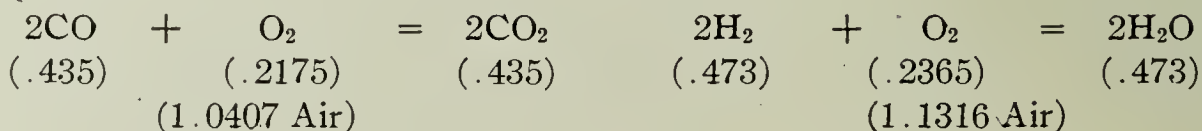
In closing, and for the sake of exactness, it seems well to include the following table, which will be found specific instead of general, and which will show the precise results of comparative study upon the few gases named. In securing these it has been found of great advantage to use the volume reactions for the oxidation of the gases present. Following the table are two examples which show the method of working for natural gas and for blue gas.

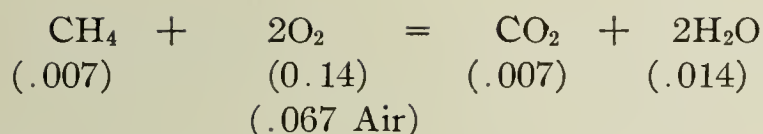
COMBUSTION DATA ON BLUE WATER GAS

ANALYSIS OF GAS:

CO	= 43.5%	Sp. gr. = .559
H ₂	= 47.3	Sp. ht. = .45
CH ₄	= 0.7	Heat content = 302 B.t.u.
CO ₂	= 3.5	Reaction temperature (theoretical) = 3470°F
O ₂	= 0.6	(Note: O ₂ in air taken as 20.9% by vol.)
N ₂	= 4.4	

100.0%





1.0407
1.1316
.0670

2.2393 Gross vol. air to burn 1 vol. gas.

Correction for oxygen content in blue gas. (.6% O₂ = .006 volumes, equivalent to .0287 volumes of air.)

2.2393
0.287

2.2106, Net volume of air to burn 1 volume gas.

2.2106 + 1 = 3.2106 cu. ft. of theoretical mixture per 1 cu. ft. gas.

$\frac{302}{3.2106} = 94.06 \text{ B.t.u. per cu. ft. theoretical air gas mixture.}$

Products of Combustion:

a.	CO ₂	$\left\{ \begin{array}{ll} \text{in gas} & .035 \\ \text{from CO} & .435 \\ \text{from CH}_4 & .007 \end{array} \right.$	<u>.477</u>
b.	H ₂ O	$\left\{ \begin{array}{ll} \text{from H}_2 & .473 \\ \text{from CH}_4 & .014 \end{array} \right.$	<u>.487</u>
c.	N ₂	$\left\{ \begin{array}{ll} \text{in air} & 1.748 \\ \text{in gas} & .044 \end{array} \right.$	<u>1.792</u>
d.	O ₂	in gas	<u>.006</u> <u>.006</u>

2.762 Cu. ft. per cu. ft. gas.

$\frac{302}{2.762} = 109.34 \text{ B.t.u. per cu. ft. products of combustion.}$

$\frac{.487}{2.762} = .1763 \text{ or } 17.6\% \text{ H}_2\text{O in products of combustion.}$

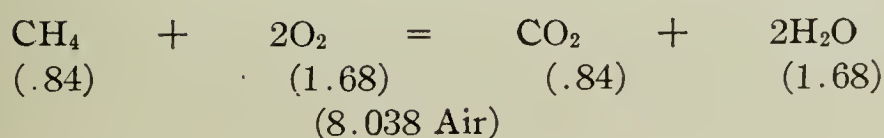
COMBUSTION DATA ON NATURAL GAS

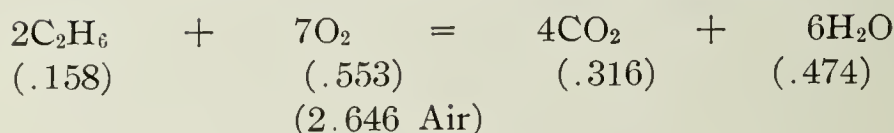
ANALYSIS:

CH₄ = 84.0%
C₂H₆ = 15.8
CO₂ = 0.2

100.0%

Specific gravity .631
B.t.u. 1126



COMBUSTION DATA ON NATURAL GAS (*continued*)

8.038

2.646

10.684 Vols. air required to burn 1 vol. gas.

10.684 + 1 = 11.684 cu. ft. of theoretical mixture per cu. ft. gas.

$$\frac{1126}{11.684} = 96.37 \text{ B.t.u. per cu. ft. of theoretical air-gas mixture.}$$

Products of Combustion.

a.	CO ₂	$\left\{ \begin{array}{l} \text{in gas} \quad 0.200 \\ \text{from CH}_4 \quad .840 \\ \text{from C}_2\text{H}_6 \quad .316 \end{array} \right.$	1.356
b.	H ₂ O	$\left\{ \begin{array}{l} \text{from CH}_4 \quad 1.680 \\ \text{from C}_2\text{H}_6 \quad .474 \end{array} \right.$	2.154
c.	N ₂	in air	8.451

11.961 cu. ft.

Products of combustion per cu. ft. gas.

$$\frac{1126}{11.961} = 94.14 \text{ B.t.u. per cu. ft. of products of combustion.}$$

$$\frac{2.154}{11.961} = .1801 \text{ or } 18.01\% \text{ H}_2\text{O in products of combustion.}$$

Comparison of	Natural gas	Blue gas	Cold clean coke producer gas
B.t.u. per cu. ft.	1126	302	128.5
No. cu. ft. air for theoretical combustion	10.684	2.21	.938
B.t.u. per cu. ft. theoretical air-gas mixture	96.37	94.06	66.3
No. cu. ft. flue gas per cu. ft. gas from theoretical air-gas mixture	11.961	2.762	1.743
B.t.u. per cu. ft. flue gas	94.14	109.3	73.6
Per cent H ₂ O in flue gas	18.01	17.6	7.16
Cubic feet per million B.t.u.	888.1	3311.0	7775.0
Reaction temperature	3370°F (?)	3470°F	2730°F
O ₂ in atmosphere = 20.9% by vol.			

Discussion

G. FITZGERALD:—What is the size of the smallest generator which can be had?

A. E. BLAKE:—You can have a standard generator 4' in diameter which is rated to furnish 2,000,000 B.t.u. of blue gas per hour. The sizes of standard generators increase by a foot in diameter, the largest having a diameter of 12' and a rated hourly capacity of 37,500,000 B.t.u. of blue gas.

W. W. OAKLEY:—What is the advisability of large holders and where is the economical point reached as to the advisability of putting in duplicate generator equipment?

A. E. BLAKE:—There must be a holder in any case. The situation is very simple when there is a steady 24-hour demand for gas or even when the working day is 10 hours, but the demand is steady. It is impossible to do without a relief holder at least, on account of the intermittent way in which the gas is made. If a single generator is used the holder must have sufficient capacity to supply the demand for gas during the period occurring about every 8 hours when the grate of the generator must be cleaned. This period may be from 30 minutes to 2 hours, depending upon the size of the generator and other conditions. Hence the advisability of having two generators, each of which may be a standby set in turn. The normal rating of such an installation would be that of a single generator, but it furnishes a much more satisfactory operating condition and it is possible to fit the installation to the demand characteristics for gas more nicely. For instance, when the hourly demand throughout an ordinary day is at a given figure which might correspond to the rating of one generator, there may be times during the day, or during the week, say in the morning, when furnaces are being started up, and after a noon-day period, or other periods constituting daily shifts in plant operation, the demand for gas may easily be doubled for perhaps an hour, when the operators are bringing their furnaces up to the working temperature. At such times, and for any other emergency, it is a simple matter to throw in the standby generator and have a temporary 100% additional production.

A MEMBER:—What means are there for eliminating the sulphur in blue water gas?

A. E. BLAKE:—The elimination of sulphur is an important item if gas is to be used in a direct-fired leer, or in any other application where the glassware can receive a frosted coating which is objectionable. Sulphur has been very thoroughly removed from illuminating gas in all our large cities where it is used, for a very long time, at least for 40 or 50 years. There are numerous acts and ordinances in the various states, counties and cities regulating the permissible sulphur content of artificial gas for domestic use. If sulphur were not removed household furnishings which have been dyed, such as draperies, wall paper, etc. would in time become bleached from the action of sulphur dioxide produced in the burning of the gas. The presence of sulphur would also be noticeable by the odor of the sulphur dioxide. You will see how important it is to thoroughly purify artificial gas in order to remove these serious objections, and therefore, you can surmise that the state of the art of gas purification has been developed to a high degree of efficiency. Blue water gas lends itself with ease to all methods of purification which are known. The commonest

method in use consists of passing the gas after scrubbing and cooling through a box in which is a series of trays, loaded with a mixture of iron oxide and shavings. At the start iron turnings can be taken, which after use are oxidized. Such an arrangement will serve to purify the gas for a very considerable period before it is necessary to replace the material with a fresh supply and permit the spent mixture to revivify by exposure for a time to the air. If it is desirable or necessary the sulphur content of any clean artificial gas can be reduced to the order of a *trace* of sulphur.

W. W. OAKLEY:—What capacity of holder would be required for a blue gas plant consisting of 2 to 4 foot generators?

A. E. BLAKE:—Depending upon the conditions of operation I would say the holder should be of 20 or 25 thousand cubic feet capacity. If storage would be desirable it might be advisable to install a 50,000 cubic feet holder, but that would be large for a plant of such size.

W. W. OAKLEY:—Would you run both sets?

A. E. BLAKE:—Both sets can be run part of the time, but each one must be shut down for cleaning after each 8 hours or so of steady operation. For so small a set, only about 20 minutes would be required for cleaning. In determining the size of an installation, however, it is essential to choose in such a way that there is always to be a comfortable margin of production capacity, or holder capacity, in order that every reasonable call for gas can be promptly met. When the operation is for 8 or 10 hours it is often advisable to install more holder capacity in place of spare generators for the reason that holder capacity is cheaper than generating capacity and since holders are simple compared to generating equipment the general expense for upkeep can be lowered. It is possible, however, and practical to keep two generators constantly under fire while one acts as a reserve ready at a minute's notice to be called into play.

A. MEMBER:—Can blue water gas be used directly from the holder under holder pressure, or is it necessary to install additional apparatus?

A. E. BLAKE:—The holder throws a pressure of about 10" water column into the distributing main. This can be made to serve for shop purposes. To my mind the systems which operate to burn blue gas and other artificial gases most suitably generally require the gas at 10 pounds pressure. In that case a suitable booster running automatically would be installed after the holder. The operating cost would only be in the neighborhood of 2 cents per million B.t.u. for the added pressure and for this cost all air piping, blowers, and all provision for natural draft, such as stacks, for the most part can be eliminated. One also gets the benefit in such systems of automatic mixing and the use of a predetermined proportion of air to gas and a single valve control. However, low pressure gas from the holder and natural draft, or fan blast, can be used satisfactorily if rigid economy is not essential.

Some time ago I ran across an account by F. W. Steere,¹ which shows a comparison between the use of a muffle and its elimination in a given furnace. I am quoting him as follows:

We might mention that we have built this type of furnace with a muffle (continuous heat treating furnace for automobile parts) to prevent the products of combustion from coming in contact with the steel, the idea of the muffle being to reduce the scaling to a minimum. After several months of comparative tests in running these furnaces with and without the muffle, we concluded that the benefits of the muffle did not warrant the additional expense in construction and operating costs. To maintain an average hearth temperature of 1650° it was found necessary to keep an average temperature in the combustion chamber of 2550° outside the muffle. The average gas consumption is 264 cu. ft. of gas per minute, the average cubic feet of gas per ton of stock being 22,970. The efficiency of the furnace was 14½%.

With the same type of furnace, running exactly the same temperature conditions and delivering the same amount of stock, without the muffle, that is, the products of combustion coming in contact with the steel, we found that the average gas consumption was 150 cubic feet of gas per minute, or 11,500 cu. ft. of gas per ton of stock, with a furnace efficiency of 26% as compared with 14½%, as stated above.

By furnace efficiency we mean the total amount of heat put into the stock divided by the total amount of heat delivered to the furnace in the gas.

Recently I have received some data which will be of interest to those who are annealing glass in leers. The Chattanooga Bottle & Glass Mfg. Co. of Chattanooga, Tennessee, is using coke oven gas on a battery of 5 leers, each leer 5 feet 6 inches wide by 75 feet long, and the fire box is 10 feet long. The inside height of the leers at the front is 14 inches to the level of the chord of the arch. The crown of the arch is 9 inches more. The front of the leers is insulated with insulating brick, also the sides and crown of the fire box. Each leer has a 24-hour production of from 7½ to 8 tons of bottles, milk jars, etc. The temperature in the fire box is maintained at from 1140°F for soda water bottles and milk jars, and about 1060°F on medicine bottles. The consumption of gas is from 625 to 650 cu. ft. per hour per leer. This would be the equivalent of from 326 to 339 cubic feet of 1125 B.t.u. natural gas per hour, or 7580 to 8140 cubic feet of natural gas per 24 hours, or 37,900 to 40,700 cubic feet for the battery of 5 leers per 24 hours. Some of this data ought to enable many glass men to draw a parallel between their own gas consumption for leers and these results which have so kindly been given to me by Mr. William H. Meacham, President of the Chattanooga Bottle & Glass Mfg. Co. in a letter dated January 29, 1923. The total sulphur in the gas being used in this case is reported as being about 8 grains per hundred cubic feet. The heat content of the gas averages about 540 B.t.u. per cubic feet.

G. FITZGERALD:—There are four sources of clean gas: natural gas, manufactured coal gas or coke oven gas, manufactured water gas and washed producer gas. What is the size of the water gas set that would

¹ "American Fuels," pp. 984, 985.

furnish gas at a competitive price with these other gases? There are many instances in which the use of manufactured coal gas is economically sound, but if this is not available one must rely either on manufactured water gas or washed producer gas. Is the gross consumption for which the use of water gas is available, at a competitive price with manufactured coal gas?

A. E. BLAKE:—Blue water gas can be made by the use of chemistry laboratory glassware, etc., if desired. You, however, are doubtless interested in knowing the size of the smallest standard unit which can be operated, as the word standard would imply, on an *economical basis* to make gas to be used for industrial purposes. The case with blue water gas equipment is practically identical with that of nearly any other kind of equipment for making gas or other commodities. To illustrate we can say that the cost of heat units delivered by the smallest commercial sized clean producer gas plant is bound to be at least somewhat higher than for a very large installation of that kind. In the case of blue water gas the size of the smallest standard generator is one having a diameter of 4 feet. Its normal rating is equal to the supply of 2,000,000 B.t.u. as blue water gas per hour. That is about the equivalent of 2000 cubic feet of natural gas per hour. The added cost of blue gas per million B.t.u. from this very small generator will depend a great deal upon circumstances, but would probably be somewhere from 5 cents to 10 cents higher than for a plant of ten times the capacity. The thing holds, I believe, in the case of steam power plants, electric generating stations, fuel oil installations, and the like. The point is illustrated, for instance, by noting that in cities like Boston, Chicago, or Philadelphia, the rate charged for gas is much lower than the rate which obtains in the smaller cities and towns fortunate enough to have even a tiny gas works to cater to their convenience, and all this when the towns and small cities are in the same regions as the larger ones mentioned.

CLAY SEWER PIPE MANUFACTURE

III—The Heat Distribution in Sewer Pipe Kilns¹

By H. G. SCHURECHT²

ABSTRACT

Purpose.—A study was made of the heat distribution in four sewer pipe kilns in order to determine means of making this as uniform as possible and thus produce pipe of uniform maximum strength and reduce the cost of firing.

Results.—It was found that the coolest portions of the kilns are along the entire bottom and on the top near the outside of the kiln. The hottest portion is usually on the top in center of the kiln. Kilns having a small diameter have a more uniform distribution of heat than those having larger diameters.

Introduction

One of the important requirements for sewer pipe is high strength since they are required to resist considerable external pressure, due to the weight of soils and traffic above them, as well as internal strains, due to the hydrostatic pressure caused by a heavy downpour of rain.

In order that pipe of maximum and uniform strength may be produced it is necessary that the kilns should be fired at a specific temperature and that the heat distribution in the kiln should be uniform. There is a certain range of temperature in which each clay develops maximum strength and if this temperature is not reached the pipe will be porous and weak. If it is exceeded the pipe will be too brittle and weak and deform out of shape.

A kiln having a very uniform heat distribution can also be fired faster and hence with less fuel than one in which this distribution varies between wide limits. During watersmoking the ware is fired at a very slow rate

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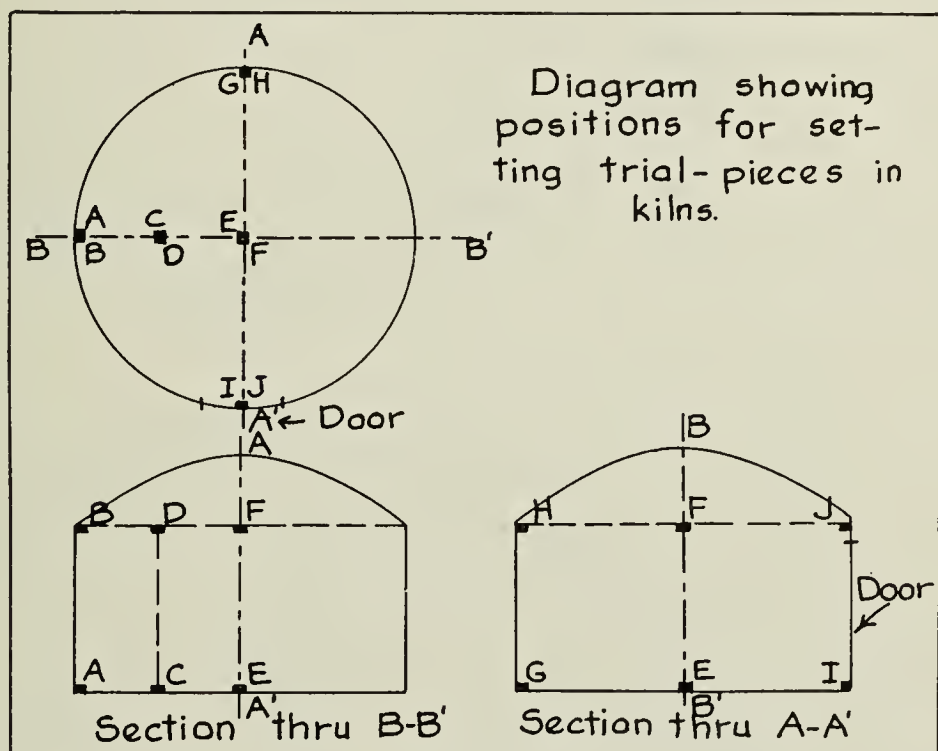


FIG. 1.

and if the coolest portion of the kiln is 100°C lower than the hottest portion, it would be necessary to continue at this slow rate of firing until

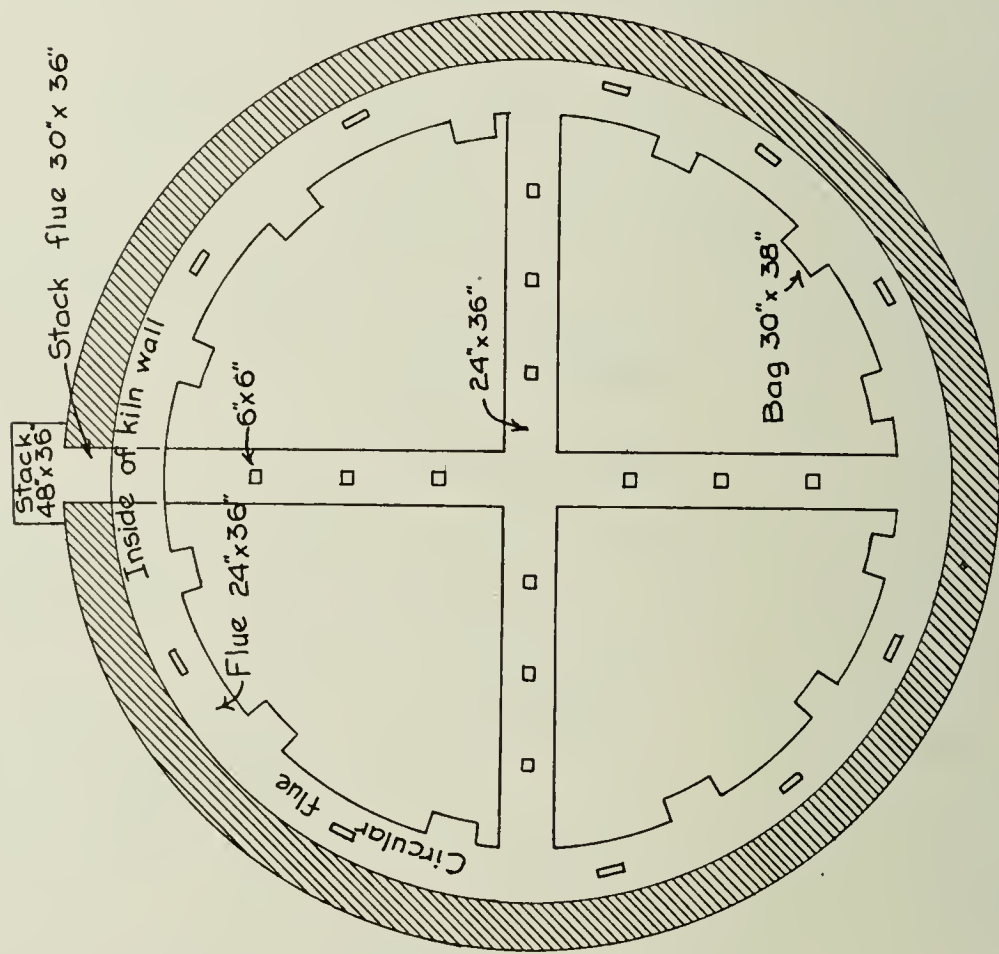


FIG. 3.—Flue system in a 35-ft. sewer pipe kiln. Cross and ring flue system. Type B.

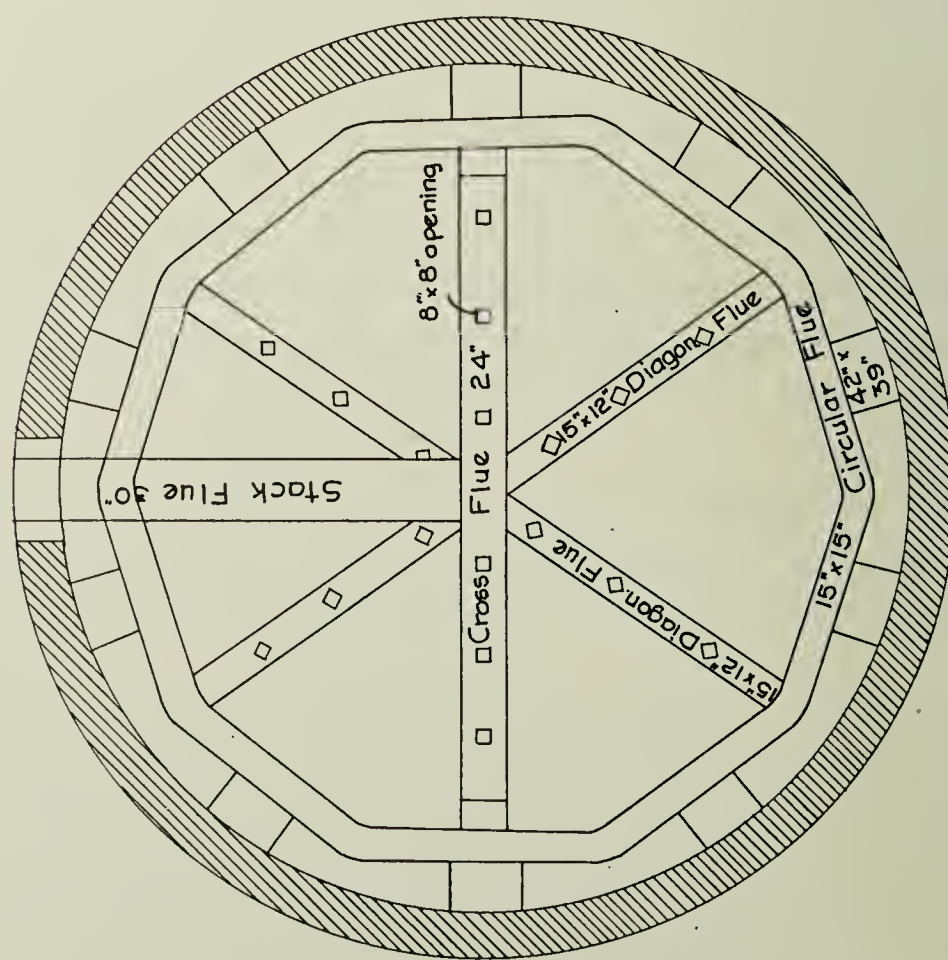


FIG. 2.—Flue system in a 34-ft. sewer pipe kiln. Cross and diagonal flue system. Type A.

the hottest portion is heated 100°C above the watersmoking temperature. A kiln with a more uniform heat distribution could therefore be water-

smoked, dehydrated and oxidized in less time than one with a wide difference in heat distribution.

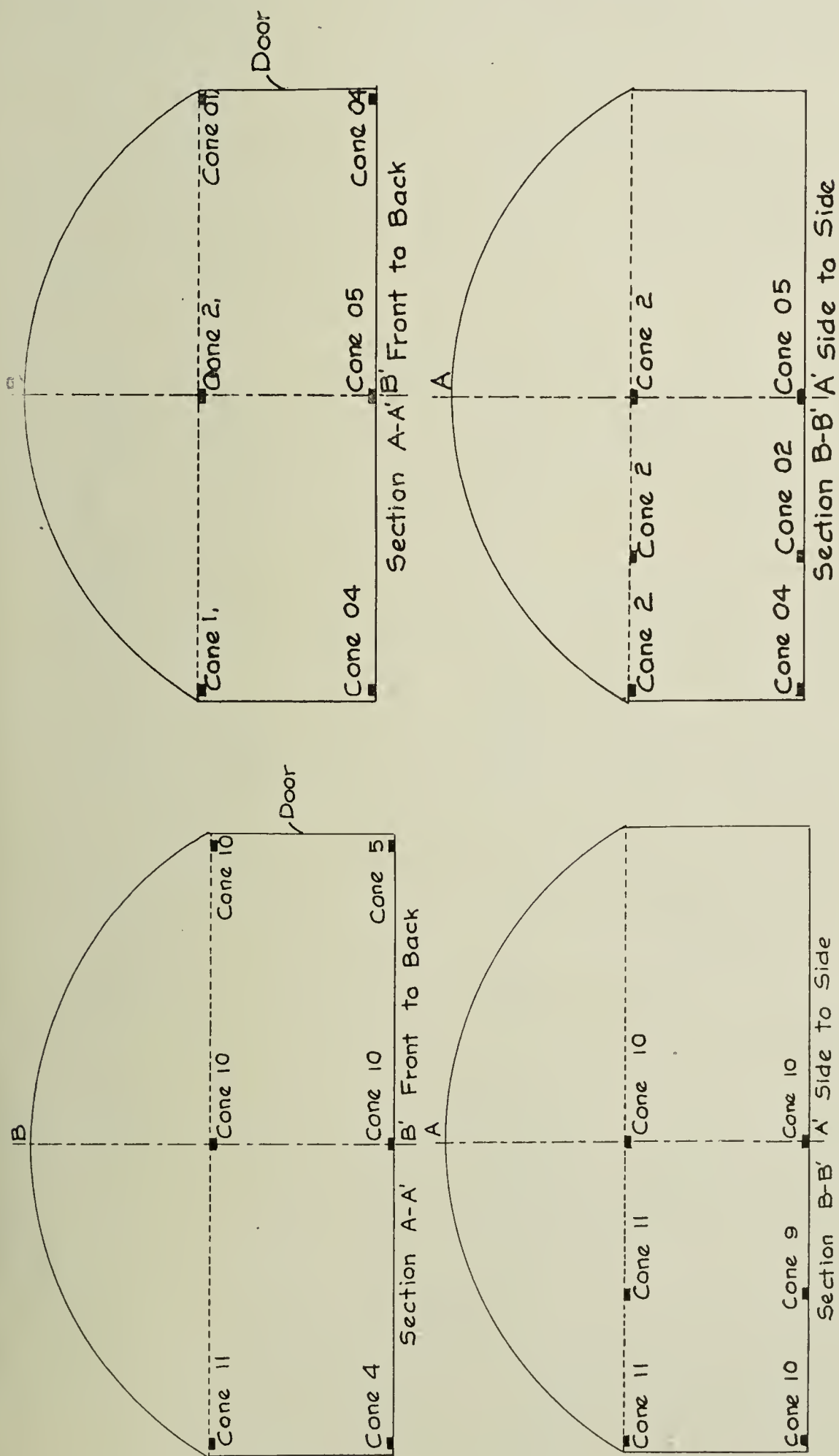


FIG. 4.—Heat distribution in a 34-ft. kiln having a flue system of the type A.

FIG. 5.—Heat distribution in a 28-ft. kiln having a flue system of the type B.

A systematic study is therefore being made of the factors governing the heat distribution in sewer pipe kilns in order to determine means of making this as uniform as possible.

Experimental Methods

4" x 6" fire clay saggers, each containing 10 cones, were placed in 10 different positions (Fig. 1) in commercial sewer pipe kilns. The cones

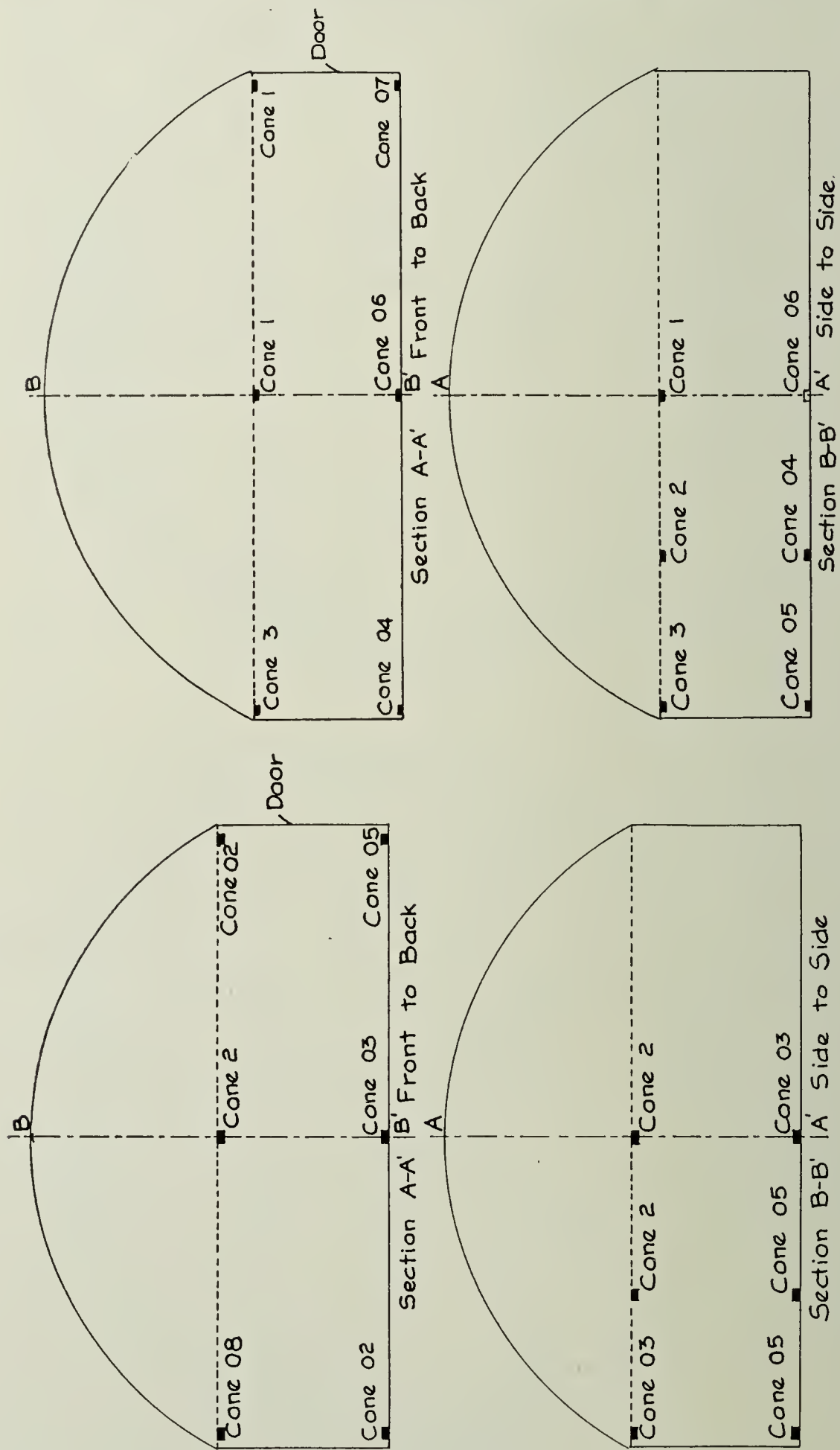


FIG. 7.—Heat distribution in a 35-ft. kiln having a flue design of the type B.

FIG. 6.—Heat distribution in a 30-ft. kiln having a flue system of the type B.

were placed inside of these saggers to protect them from the reducing kiln atmosphere and salt fumes which would cause them to deform prematurely

This investigation has been conducted in four kilns. One had the type A flue system (Fig. 2). The other three had the type B flue (Fig. 3). The first kiln had an internal diameter of 34 feet and the last three had internal diameters of 28 feet, 30 feet and 35 feet, respectively. The first was fired to cones 10-11 and the last three to cones 2-3.

After the kiln had been fired, the temperatures reached in the different portions were obtained by noting what cones had deformed. The percentages of the kiln volume falling within different ranges of temperature were then calculated and these figures were used to compare the heat distribution in the different kilns.

Experimental Results

The temperatures obtained in the different portions of these kilns are shown in Figs. 4, 5, 6 and 7.

In Figure 4 is shown the heat distribution obtained in the 34-foot kiln having a flue system of the type A. Although this kiln gave the best results of any tested, the temperatures on the bottom in positions G and I were 5 cones lower than the hottest portion of this kiln. These positions are directly in front of the door and "backout" of the kiln and their lower temperatures are apparently due to heat lost through the thinner walls at these places. Using thicker wickets especially in the lower half of the door would reduce the escape of heat at these points and raise the temperatures of these portions of the kiln.

The three kilns fired to cones 2-3 all showed a poorer heat distribution than that fired at cones 10-11. Since kilns fired to high temperatures usually have a more uniform distribution of heat than those fired at lower temperatures, this would partly explain why the kiln fired at cones 10-11 gave better results than those fired at cones 2-3.

In the three kilns fired at cones 2-3, the coolest portions were found to be along the entire bottom and also on top near the outside. The hottest portion is on top in the center. This is partly due to the fact that the area of the brick walls through which heat escapes is much greater for the portion around the outside of the kiln than it is for that portion in the center. It was also found that the kilns with a small diameter had a more uniform distribution of heat than those with larger diameters.

The percentages of the kiln volume, falling within different ranges of

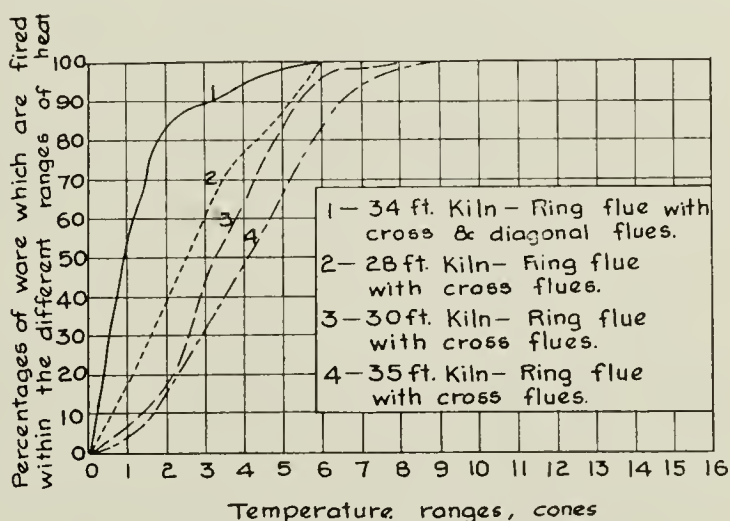


FIG. 8.—The heat distribution in sewer pipe kilns.

temperature are shown graphically in Figure 8. These percentages were calculated in terms of that volume below the sides of the crown since the crown is seldom filled with ware. The kilns having the upper curves have a more uniform distribution of heat than those having the lower curves.

By examining these curves it is seen that the heat distribution in kiln 1 is far superior to that obtained in kilns 2, 3 and 4. Kiln 2 which has a diameter of 28 feet is heated more evenly than kilns 3 and 4 which are 30-foot and 35-foot kilns, respectively, with the same flue system.

With kiln 1 it is possible to vitrify 90% of the ware if the pipes are made with a body having a vitrification range of 3 cones. The proportions of the ware which would be vitrified in the other kilns are 60 per cent in kiln 2, 44% in kiln 3 and 32% in kiln 4.

Summary and Conclusions

A study was made of the heat distribution in four sewer pipe kilns since in order to manufacture pipe of uniform strength they must be fired in kilns having almost a uniform heat distribution.

It was found that the coolest portions of the kilns are along the entire bottom and on the top near the outside. The hottest portion is usually on the top in the center of the kiln.

There is a large variation in the heat distribution in different kilns. Even those having the most uniform distribution have cool portions in front of the doors due to the rapid escape of heat through the thin walls at these points.

Kilns having a small diameter have a more uniform heat distribution than those having larger diameters.

NOTE: The writer wishes to acknowledge his indebtedness to Dr. E. W. Tillotson for helpful suggestions during the progress of the work and to the sewer pipe manufacturers for their coöperation in conducting these tests.

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THE FIRE BRICK MATERIALS OF PENNSYLVANIA¹

BY GEORGE H. ASHLEY

ABSTRACT

Pennsylvania produces over 40% of all clay fire brick and over 70% of all silica fire brick made in the United States. In 1920 Pennsylvania produced and sold fire clay worth nearly two million, fire clay brick worth nearly twenty-two million, and silica brick worth over ten and one-half million, a total of thirty-four and one-half million dollars worth of brick and clay.

Three kinds of material are used for the manufacture of this fire brick. (1) Soft fire clay from one horizon northwest of Pittsburgh and from the "main clay" of the Pittsburgh bed south of Pittsburgh. (2) Hard or flint clay which occurs in many counties of the State. The hard clays are described as occurring at a limited number of horizons in the Allegheny formation or "Lower Productive Coal Measures," as being irregular in thickness and distribution, ranging from a feather-edge to fifteen or twenty feet in thickness and being of two types, "block" clay in which the structure is homogeneous, and "nodular" clay in which the structure is gnarly or knotty. Brief reference is made to the principal flint clay deposits of the State. (3) The third source of material for fire brick is ganister rock, a pure white quartzite occurring as a massive bedded sandstone at the base of the Silurian series and exposed abundantly in the zig-zag ridges across the central part of the State and as a similar white quartzite at the base of the Cambrian in the southeastern part of the State. A series of tests of flint clays and of soft clays used to mix with the flint clays is appended. These are derived mainly from Clearfield County which is the leading flint clay county.

Introduction

The value of the raw clay and finished clay products produced in the United States annually is exceeded in value among the mineral industries only by coal and petroleum. When it is recalled that the value of clay fire brick manufactured is one-fifth that of the whole industry, and that Pennsylvania produces over 40% of all clay fire brick, and over 70 per cent of the silica fire brick made in the United States, it should be of interest to know how and where fire clays and ganister occur in Pennsylvania.

In 1920 Pennsylvania produced and sold fire clay worth \$1,946,772, fire clay brick worth \$21,929,602, and silica brick worth \$10,629,769, a total of \$34,506,143.

Kinds of Materials Used

Three kinds of material are used for the manufacture of fire brick in Pennsylvania, soft fire clay, hard or "flint" fire clay, and ganister. Fire clay is a clay comparatively free from iron and alkalies, not easily fusible, and hence used for making brick to line furnaces. Ganister is a highly refractory siliceous sedimentary rock used for furnace lining or crushed for use in making silica brick.

Soft Clay.—The soft clay used in making fire brick in this State occurs in beds in or under the coal beds. Formerly all clays found under the coal

¹ Presented before the Refractories Division, Pittsburgh Meeting, February, 1923.

beds were called fire clays. As a matter of fact such clays are usually more refractory than clays or shales found elsewhere in the same series of rocks. There is therefore some reason for calling them "fire clays." But experience has shown that as a rule such clays are not sufficiently refractory to meet many or most of the demands made today for a high-grade fire brick. These clays may soften at Seger cones 15 to 25, while the demand may be for brick that will not soften below Seger cone 30. The soft clays are used for fire brick not subject to excessive heat, and especially for brick able to resist abrasion. These clays find large use for mixing with non-plastic but more refractory fire clays, the proportions of the mix being varied with the use to which the brick is to be put.

The soft clays, or "underclays," are commonly drab or blue in color when fresh, but white when weathered; and vary from fair to good in plasticity. They commonly occur as beds directly under the coal or as relatively thin partings between the benches of a coal bed, and are very regular in thickness and character from place to place. The clay beds may vary from top to bottom, the bottom being generally more sandy than the top, but in their horizontal extent beds of clay may cover thousands of square miles, and be more regular and persistent than the coal beds that overlie them.

The soft clays occurring as partings in the coal beds are more regular than the underclays; some beds a fraction of an inch thick can be followed over hundreds or even thousands of square miles. The "main clay" of the Pittsburgh bed is a notable example. This lies directly on top of the mined coal in the Pittsburgh district, separating it from the so-called "roof coal." The thickness is nearly everywhere from 6 to 12 inches, and commonly between 8 and 10 inches.

The soft clays are commonly less than 10 feet thick and probably average less than 4 feet, but locally they may be 20 to 30 feet, or even more. The thickness is more or less characteristic of the beds; certain beds, such as that under the Lower Kittanning or "B" coal, are characteristically thick, other beds are characteristically thin.

Flint Clay.—"Flint clay" is a term used to designate a clay rock that has few of the properties ordinarily ascribed to clay. It is not soft, but so hard that it will ring under the hammer. It is not plastic, but must be mixed with a plastic clay to be molded into brick. It does not soften when wet as do most clays, but will continue to break down into smaller and smaller splintery fragments. Where a flint clay crops out in roads its weathered fragments may crunch under the wheels of a wagon like so much broken glass. Instead of softening at Seger cone 15 to 25 such clays will commonly withstand temperatures up to cones 25 to 35. The flint clays are commonly light drab in color, but range to black or other shades. They break with a conchoidal or hackly fracture much after the manner of

flint (quartz). They differ chemically from the soft clays in their freedom from the so-called fluxes and in their proportions of silica and alumina. The best flint clays contain less than 3% of iron oxide, lime, magnesia and alkalies taken together, in contrast with the soft clays which usually contain over 5% of those substances. This statement refers particularly to the high-grade flint clays. Flint clays with a larger percentage of iron, in particular, are not uncommon, and in many places the unweathered clay contains a large percentage of iron oxide which gathers into "iron balls" where the clay is weathered. The weathered clay has value because the iron balls can readily be removed. Chemically the flint clays have almost the composition of kaolinite. Locally they may carry more than the normal percentage of alumina and become potential ores of aluminum. This is due to the presence of diaspore or gibbsite—aluminum hydrates.

There are two types of flint clay, block and nodular. In "block" clay, the structure is homogeneous and the grain appears as smooth and fine as in a siliceous flint; in the other the clay occurs in nodules. "Nodular" clay has sometimes been assumed to be of low grade. On the contrary the high alumina clays appear to be commonly of the nodular type.

Flint clay occurs in beds usually in association with soft clay. The association is commonly such as to suggest that the flint clay is the result of changes taking place in the soft clay. It has been suggested that a flint clay consists of tabular crystals of kaolin, and because of this crystalline condition the beds are not plastic and do not soften when exposed to the weather. The crystals are extremely fine—so fine that in some instances doubt has been expressed as to whether the rocks were crystalline or colloidal. Evidences of the possible secondary character of the flint clay are: first, the extremely irregular shape of many of the deposits; second, in the same bed the flint clay at one point may be above the soft clay, at another below, and at still another between two benches of the soft clay; third, in certain deposits flint clay appears to be confined to the zone of weathering. A bed that yields excellent flint clay at the surface may, a short distance in the hill, yield only soft clay. Notwithstanding the irregular character of individual beds, the deposits appear to be confined to certain few horizons as though the original clays in those horizons differed in some essential from other clays. Furthermore, in a few instances flint clays lie in fairly regular beds having considerable extent. In northern Beaver County, Pennsylvania, a flinty clay occurs so persistently a short distance above the Upper Freeport coal and over so large a territory as to have proved a valuable key rock in working out the geology of that region.

Most of the deposits with which the writer is familiar are extremely lenticular. For example, a drill hole in Clearfield County penetrated 5

feet of high-grade clay, but an entry driven so as to cut the drill hole showed that the clay pinched out in less than the width of the entry. Experience has shown that the flint clay below the Lower Kittanning or "B" coal is especially likely to have a distinct relation to the surface. Many mines opened in this bed started with 5 to 15 feet of clay which pinched out in a few hundred feet on driving into the hill. On the other hand, here and there, mining has revealed bodies of clay that appeared to maintain their thickness and quality regardless of distance from outcrop or depth of cover, as at Woodland, Clearfield County, Pennsylvania.

Deposits of flint clay may be 20 feet thick or more, but usually are less than 5 feet. The thickness of both flint and soft clay combined does not seem to bear any relation to the thickness of the overlying coal. In many mines on the thick and regular bed of Mercer fire clay the overlying Mercer coal is only a few inches thick or has disappeared altogether. In the same mine the coal may vary from a few inches to 2 or 3 feet apparently without affecting the thickness or quality of the clay.

Ganister.—Ganister is a name given to certain flux-free sandstones.

This material is used in the form of stone dressed to the desired shapes, as brick, and as sand to line furnaces and ladles. The largest use of ganister is in the manufacture of silica brick for lining glass furnaces and furnaces making steel by the acid process.

Experience has shown that the best material for brickmaking is quartzite, a sandstone in which the quartz grains are cemented by secondary silica, so that the rock is more firmly cemented and less porous than before. Such a rock when crushed breaks down, not to round grains of sand but to splintery fragments, because the rock fractures across grains and cement alike. The splintery character of the ground material gives binding power and strength to the brick.

Although certain of the sandstones found in the coal measures have been used as ganister, the most satisfactory ganister found in Pennsylvania is in two beds of quartzite, each several hundred feet thick and of great extent. Further, it has been found that the best rock is that which has broken away from the main ledges and now mantles the subjacent hill slopes. The weathering to which these blocks have been subjected appears to have removed some of the iron oxide found in the unweathered rock.

Geological Occurrence of These Materials

If, beginning with the rocks in which are found the oldest known fossils, all geologic time be divided into ten ages, the first five may be designated from the bottom up as Cambrian, Ordovician, Silurian, Devonian and Carboniferous. The last includes the coal measures. The rocks of these ages underlie nearly the whole of the Commonwealth of Pennsylvania and are tens of thousands of feet thick. Within this great series of rocks

the refractory materials to which reference has been made are confined to a few hundred feet at three separate horizons. Ganister is obtained in Pennsylvania almost exclusively from two bodies of massive sandstone or quartzite, one at the base of the Cambrian, the Chickies quartzite, and the other at the base of the Silurian, called the Medina (Tuscarora) sandstone. The Chickies quartzite, named from Chickies Rock on the Susquehanna River above Columbia, crops out in the southeast part of the State. The Medina sandstone has a very wide extent, underlying all of western New York, two-thirds of Pennsylvania, and all of eastern Ohio.

The fire clays used in Pennsylvania come almost entirely from a thin series of rocks near the middle of the Carboniferous known as the Allegheny formation. This formation corresponds to what was formerly called "Lower Productive Coal Measures." It consists of shales and sandstones with from 5 to 12 coal beds, each underlain by a bed of clay. These beds of clay furnish the soft clay of the State, and it is in association with them that the flint clays are found. The Allegheny formation is commonly divided into three members: the Freeport at the top contains an upper and lower coal, each underlain by clay; the Kittanning member contains usually three coals, an upper, middle, and lower; and the Clarion contains two coals, the Clarion and Brookville. Of the soft clays associated with these coals, that under the Lower Kittanning has proved of most value. It is usually the thickest clay of the group, and in general is more regular and of better quality than the others. Locally the other clays are of good thickness and quality.

The flint clays are mainly derived from three horizons. The highest known as the Bolivar clay, occurs below the Upper Freeport coal. The second, the Clarion, occurs a short distance below the Lower Kittanning coal, though sometimes separated from the Lower Kittanning underclay by many feet of shale. The third horizon is at the base of the Clarion member, or a little below. Recent work has disclosed some confusion in the identification of the rocks at or below the base of the Allegheny formation, so that it is not quite certain whether we are dealing with one bed or two; in other words, whether the lowermost flint clay is at the base of the Clarion member or in the Mercer member down in the underlying Pottsville, or whether there are two clays, one at each of these horizons.

Distribution

Soft Clays

The use of soft clays for making fire brick without mixture with flint clays is confined mainly, if not entirely, to the western end of the State. There are two centers of such use, one around the mouth of Beaver River, the other on Monongahela River near Monongahela City.

In the Beaver district clay is obtained locally from below the Lower Kittanning or "B" coal. The part of the bed used is 6 to 8 feet thick, the lower part being too sandy. Brick from this clay is suitable for use in the upper part of furnaces where high resistance to abrasion is necessary. They will not stand the high heat of the bottom of the furnace. There are a half dozen or more plants in the Beaver district, some of which also use flint clays from the center of the State. Plants are located around Beaver, Rochester, and New Brighton, Conway Station, Monaca, Vanport, and elsewhere.

The fire brick plants on Monongahela River use the clays from the waste heaps or gob of mines on the Pittsburgh coal. This clay, which makes the parting between the main coal and the overlying "roof coal," is from 6 to 10 inches thick. The clay is used principally for making sleeves, nozzles, and runners for steel works. It has been mined at Manown, Watson Station, and Courtney.

Soft clays used as a bond with flint clays are in general mined close by the fire brick plants wherever those plants are situated.

Flint Clays

Good flint clays are rather widely distributed over the coal measure area of the State. The leading districts are in Clearfield, Center, Clinton, Fayette, Westmoreland, Clarion, Armstrong, Cambria, and Indiana counties, with scattered plants in other counties. Probably the most valuable of the clays is that at the base of the Allegheny formation or Mercer horizon. The Bolivar clay occurring beneath the Upper Freeport coal comes next, and the Clarion clay under the "B" coal is third. Locally flint clays occur under other beds and above the Upper Freeport coal. A brief reference to the principal producing areas by counties follows:

Armstrong County.—The Mercer clay has long been mined in northern Armstrong County at St. Charles, where it is 6 to 10 feet thick, including $2\frac{1}{2}$ feet of flint clay. At the toe of Anthony's Bend, above Climax, the clay is only 75 feet above the creek and 12 feet thick, including both soft and hard clay. The Clarion clay is a semi-plastic clay one mile northeast of Kittanning. Both the Clarion, Lower Kittanning, and Upper Freeport clays are mined in this county, but only locally carry flint clay. Flint clay was formerly mined at Manorville from the Bolivar horizon. The soft clays of this county are much used for bonding flint clays, and are used alone to a small extent for fire brick.

Cambria County.—Cambria County has produced some flint clays from the Mercer horizon in South Fork district. The clay is up to $4\frac{1}{2}$ feet thick, and overlain by a few inches of coal. Flint clays occur at the horizon of the Bolivar bed and within 100 feet above it, and have been tested around Johnstown and farther north in the county. Several firms

at Johnstown are making fire brick, using both local clays and clay from South Fork.

Cameron, Elk, and Clinton Counties.—There are fire brick plants in Cameron, Elk, and Clinton counties, but the source of the raw material is uncertain, as these counties have not been studied in recent years in detail. Hard clay 4 to 9 feet thick, variously described as belonging to the Sharon horizon at the base of the coal measures, or at the Mercer horizon somewhat higher up, has been worked at Cameron, Cameron County, in the neighborhood of Benezette, between Benezette and Rock Hill, and on Laurel Run, in Spring Creek township, Elk County. The Mercer clay, or a clay at the base of the Allegheny formation, is being worked at Farandsville and Queens Run, Clinton County, and a hard clay supposed to be under the Middle Kittanning or "C" coal is being mined on Tangascootack Creek in Clinton County.

Clarion County.—The Mercer fire clay has been mined at Climax and St. Charles on Redbank Creek, on the boundary between Clarion and Armstrong counties. The most widespread clay in Clarion County is the "Clarion" clay under the Lower Kittanning or "B" coal. This clay is fairly persistent over a belt 3 to 5 miles wide along Clarion River in the vicinity of Clarion town. It has been mined at Sligo and at several places near Clarion Junction and Piney, and its outcrops in the roads reveal its presence over a broad area. As seen in some of the strippings the flint clay appears to be very irregular, occurring in places as great irregular masses in the soft clay. The thickness ranges from 2 to 5 feet.

This clay is now being extensively mined $2\frac{1}{2}$ miles southeast of Clarion on the Lake Erie, Franklin and Clarion Railroad near the Harvey mine on the Dean Klahr farm, by the Clarion Refractories Company. The flint clay will average 4 feet, with a maximum thickness of 9 feet. It is overlain by semi-flint 5 feet thick, and 20 feet above that is about 6 feet of soft clay under the Lower Kittanning coal. Clay has been mined at Lucinda 8 miles north of Clarion for 30 years or more. This clay is shipped to Ohio for furnace use. It is reported to be from 8 feet to a feather edge in thickness.

Clearfield County.—Probably the leading flint clay county of the State is Clearfield. Separate figures for fire clay are not available, but in 1920 the terra cotta and fire clay production in this county was valued at \$8,087,900. This does not include the value of clay shipped for use out of the county. The principal deposits are in Ferguson, Pike, Bradford, Boggs, Decatur, and Karthaus townships. In Ferguson township the Mercer clay is being mined at Lumber City a short distance above river-level. The flint clay is 6 feet thick or more. In Pike township flint clay is mined at a number of places around Stronach where the "nodular" clay is from a knife edge to 6 feet thick, and the "block" clay below from

2½ to 7 feet thick. Up Anderson Creek above Clearfield in a number of mines the flint clay is from 2½ to 10 feet thick. On Hogback Run the bed is reported to show locally as much as 8 feet of nodular clay overlying 11 feet of block clay. In places this changes to as high as 11 feet of nodular clay over 7 feet or more of block clay.

Flint clay is found at several horizons around Clearfield but apparently is not so high grade as farther east. The works at Clearfield are therefore mainly on the soft clay, or are using flint clay shipped in. Fire clay is mined at many places along Clearfield Creek, including Clearfield Junction, where two beds have been mined, Krebs Station where the Clarion clay is being mined, Faunce, Chase, and other points. At most of these places the clay mined is at the Mercer horizon. The flint clay portion of the bed is from 2 to 6 feet thick, overlain by thin Mercer coal.

In Bradford township flint clay has been or is being mined at Barrett Station, Mineral Spring, Woodland, Bigler, and over wide areas south of the last two places, and outcrops at many other points in the township. Both the Mercer and Clarion beds are mined. The Mercer bed is the more persistent and valuable, having a maximum thickness of 10 or 12 feet, though the portion mined and the average thickness will commonly range from 2½ to 4 feet.

Flint clay has been found at many places in Boggs township, especially west and southwest of Blue Ball, and at many points in the Morgan Run drainage.

The northwest corner of Decatur township around Burley is a nest of mines. The Mercer clay here, as west of Blue Ball, is near the top of the hill and has been extensively stripped though most of the workings are underground. In general the flint clay of this district is from 6 to 8 feet thick, though locally reaching 12 to 15 feet.

Flint clay crops out or is found by drilling over a considerable area in eastern Woodward township. Around Westover in Chest township is a small area of flint clay under the Upper Kittanning or C' coal.

Centre County.—Flint clay at the Mercer horizon has been worked from an early day at Sandy Ridge and Powelton in Centre County. The flint clay is from 2 to 4 feet thick, associated as usual with soft clay. Fire brick has also been made at Clarence and Orviston in the same county, but the writer has never examined the clay at these points.

Fayette and Westmoreland Counties.—The flint clay in these counties is localized in three districts. The first is where the Fayette anticline brings up rocks of Allegheny age on Youghiogheny River and Sewickley Creek. The second district is along the western foot of Chestnut Ridge where the same rocks are brought up to the surface by the upturning along the ridge. The third district is along Kiskiminitas River where the clay in the Allegheny formation is exposed again.

In the first district mining centers around Layton Station, the mines being in the Bolivar clay and in the clay below the Lower Kittanning coal. Some clay has also been mined about 130 feet above the Upper Freeport coal. At Layton there is from 8 to 12 feet of hard clay over soft clay, the whole bed having a thickness of 6 to 20 feet.

Mining on the western flank of Chestnut Ridge has extended for a long distance in Fayette County and in Westmoreland County to Conemaugh River. Among places of special note are Bailey's Point below Bear Creek Station, Henninger Mills near Dunbar, Pechin Station, Mt. Brad-dock, Lemont Furnace, and White House near the south State line.

The flint clay is mined from the Bolivar and Mercer horizons. At most of these places the flint clay has a maximum thickness of 12 or 15 feet. Mining as a rule has been confined to the outcrop because experience has shown that beyond the zone of weathering the clay contains too much iron, but within that zone the iron has been brought together in the form of "iron balls," which are easily separated. The type locality of the Bolivar clay is at Bolivar where Chestnut Ridge is cut by Conemaugh River. The flint clay has been mined here extensively and has a maximum thickness of over 20 feet. Clay has been mined still farther north in Indiana County along the west flank of Chestnut Ridge at the Mercer horizon and averages 11 feet thick. The clays from this belt along the western side of Chestnut Ridge have been used largely in making brick for building beehive coke ovens. The Bolivar clay has also been mined at Salina farther down Kiskiminitas River, the flint and soft clay together being from 6 to 13 feet thick. The clay is irregular in thickness, varying from 12 feet to 2 feet within the same mine.

Indiana County.—Clay 3 to 11 feet thick has been mined at Black Lick from the Mercer horizon; and on the west slope of Chestnut Ridge $1\frac{1}{2}$ miles east of Black Lick.

There is little doubt but that detailed studies will reveal flint clays or soft clays suitable for refractory brick at many other places in the State.

Ganister

Occurrence.—As already pointed out ganister is obtained from two formations, the Medina (Tuscarora) sandstone or quartzite, and the Chickies quartzite. The Medina (Tuscarora) sandstone at the base of the Silurian lies several thousand feet underground in the coal fields of the State. Between the Allegheny Front and the Cumberland-Lebanon-Lehigh Valley it is brought to outcrop by folding of the strata and is the principal ridge maker. In most of the ridges of that district the sandstone is more or less turned up or vertical. These ridges zigzag across the central part of the State, forming a line of outcrop hundreds of miles long.

The physical character of the sandstone varies from place to place.

The supply of material for silica brick has come mostly from the sandstone talus on the ridge slopes. The talus is not present everywhere on the slopes, and not all of it is valuable for making brick.

The second source of ganister, the Chickies quartzite, occurs only in the southeast corner of the State, that is, southeast of the Cumberland-Lebanon Valley. This quartzite has a fairly extensive outcrop in that region but to date has been used only in a minor way for the manufacture of brick.

The counties best known for the occurrence of ganister are Blair, Huntingdon, Centre, Mifflin, and Juniata. Ganister has been quarried recently at Bedford and Madley, Bedford County, Hollidaysburg, Blair County, and Mount Union, Huntingdon County. The ganister rocks of Pennsylvania have recently been studied in detail by Professor Moore, both in the field and laboratory. It is hoped an abstract of his report may be issued before long.

Reserves

Although the quantity of ganister occurring as talus or broken blocks on the mountain sides may be seriously depleted in a few decades the quantity of unweathered quartzite is practically limitless. It remains to be seen whether the unweathered quartzite will prove as suitable for silica brick as the weathered material now forming a mantle of talus over the ridge slopes.

It is difficult to estimate closely the reserves of flint clay. The deposits are so small, scattered, and irregular that only the crudest estimate is possible. It may safely be said that, including areas not yet tested but reasonably certain of being productive, there is enough flint clay in sight to supply the demand at the present rate for 25 to 50 years. Large areas in northern Clearfield and adjoining counties may prove to contain large reserves of flint clay, perhaps sufficient to meet the demand for the next 100 years. The State Survey plans to make a detailed investigation of all the flint clay areas of the State.

Character of Clearfield County Flint Clay

When the writer was making a detailed geologic map of southern Clearfield County several years ago, samples of flint clay in the area were collected by Mr. J. H. Hance. These samples were tested by the United States Bureau of Standards. The results are given in the following tables.

SOURCE AND CHARACTER OF CLEARFIELD COUNTY FIRE CLAY SAMPLES

1. Jno. Brotherlin mine, Faunce. A refractory flint fire clay which retains a porous structure at 1475°C.
2. Good mine, Morgan Run. A refractory flint fire clay which retains a porous

structure at temperatures up to 1475°C. Mixed with a plastic refractory clay it may be used in the manufacture of fire brick.

3. Faunce mine, Faunce. A refractory flint fire clay which retains a porous structure at temperatures up to 1475°C. Mixed with a plastic refractory clay it may be used in the manufacture of fire brick.

4. Cornwath mine No. 2, underlying coal, Cornwath. A fairly plastic buff burning fire clay which vitrifies at 1150°C and becomes vesicular at 1180°C. It may be used in the manufacture of porous building brick. Has no value in manufacture of refractories.

5. Soft clay, Krebs. A plastic buff burning fire clay which vitrifies at 1200°C. It may be used in the manufacture of buff colored building brick. It may be used in the manufacture of low grade refractories.

6. Shale bank, Krebs. A plastic buff burning clay of low refractoriness which vitrifies at 1175°C. It would be of value in the manufacture of building brick. It has no value in manufacture of refractories.

7. Ross mine, Lumber City. A refractory flint fire clay which retains a porous structure at temperatures up to 1475°C. Mixed with a plastic clay it may be used in the manufacture of fire brick.

8. Ross-Bloom mine, above Curwensville. A refractory flint clay which retains a porous structure at 1475°C, although its softening point (cone 32) is low for materials of this type. Has value in manufacture of refractories.

9. Hard clay mine, Stronach. A refractory flint clay which retains a porous structure at 1475°C. May be used in the manufacture of refractories.

10. Nodular clay, Stronach. A refractory flint fire clay which when mixed with a plastic refractory clay may be used in the production of fire brick.

11. Soft clay mine, Stronach. A buff burning plastic fire clay which vitrifies at 1150°. It may be used in production of building brick, etc., but has no value in the manufacture of refractories.

12. Shimmel mine, Wallacetown. A very refractory flint fire clay which retains a porous structure at high temperatures. When mixed with a plastic clay it may be used in the manufacture of refractories.

13. Upper hard clay, Woodland mine, Woodland. Refractory flint fire clay which retains porous structures at high temps. May be used in manufacture of refractories.

14. Soft clay, Shimmel mine, Wallacetown. Buff burning fire clay of somewhat low plasticity and vitrifying at 1180°C. May be used in production of low grade refractories or of building brick.

15. C' clay, middle hard, Plane mine, Woodland. Flint fire clay which remains porous at 1475°C, although its softening point (cone 31) is somewhat low for the production of high grade refractories.

16. Lower soft clay, Woodland mine, Woodland. Refractory plastic fire clay which burns to dense structure at 1450°C, and has a high softening point (cone 32) for a plastic clay. Has value as plastic bonding clay for manufacture of refractories.

17. Upper low grade hard clay, Woodland. Refractory flint clay which remains porous at 1475°C, although the softening point (cone 30) is too low for manufacture of No. 1 refractories.

18. Lower clay 16½ inches thick and 1 foot below A coal. Soisson mine, S. Sandy River, Bolivar, Westmoreland County. A refractory plastic fire clay vitrifying at 1350°C. This material may be used as bond clay in the manufacture of refractories.

TABLE I
CHARACTER OF CLEARFIELD COUNTY FIRE CLAYS

Sample number	Molding behavior	Water of plasticity in per cent dry weight	Volume drying shrinkage in per cent dry weight	Softening point in Seger cones
1	Non-plastic	12.4	5.1	33+
2	Non-plastic	12.1	4.8	33
3	Non-plastic	12.3	4.8	33
4	Fair plasticity	18.8	13.7	25
5	Very fair plasticity	18.6	13.6	26
6	Good plasticity	..	..	8
7	Non-plastic	13.2	5.4	33
8	Non-plastic	13.7	5.5	32
9	Non-plastic	12.7	4.9	32+
10	Non-plastic	13.2	3.5	33
11	Very fair plasticity	20.3	14.1	15+
12	Non-plastic	13.3	5.9	33+
13	Non-plastic	12.2	4.6	33
14	Slightly plastic	18.1	13.0	29
15	Non-plastic	16.1	7.8	31
16	Fair plasticity	16.8	10.6	32+
17	Non-plastic	12.3	4.3	30
18	Very fair plasticity	18.2	12.6	29

TABLE II
POROSITY AND BURNING SHRINKAGE OF CLEARFIELD COUNTY FIRE CLAYS AT DIFFERENT TEMPERATURES (CENTIGRADE)

a = Per cent porosity

b = Per cent volume burning shrinkage in terms of dry volume

Sample No.		1000°	1030°	1060°	1090°	1120°	1150°	1180°	1210°	1240°
1	a	..	25.5	25.4	25.7	25.1	24.2	23.3	23.2	23.3
	b	..	12.1	12.2	12.9	13.7	15.5	16.3	16.8	17.2
2	a	..	30.0	29.7	29.3	29.4	28.9	28.6	27.4	27.4
	b	..	4.0	5.7	7.0	7.6	7.5	8.9	9.4	10.2
3	a	..	25.8	25.7	25.2	24.6	24.7	23.8	24.5	24.2
	b	..	9.8	10.8	11.3	12.1	12.6	12.5	12.8	12.0
4	a	22.7	21.8	18.4	15.4	13.0	9.6	12.7	17.7	21.8
	b	5.6	7.8	10.4	13.5	15.3	16.5	8.1	2.2	..
5	a	..	26.1	24.5	22.3	19.6	16.4	13.2	11.0	9.6
	b	..	4.2	6.1	8.2	10.5	13.8	15.1	12.3	7.6
6	a	..	28.0	24.9	19.2	13.9	12.4	9.6	8.9	7.6
	b	..	1.0	5.1	10.3	14.7	16.9	18.6	18.8	18.0
7	a	25.4	25.8	24.9	24.4	24.3	23.4	23.1	22.6	22.2
	b	9.1	10.3	10.6	12.4	13.1	13.2	13.8	13.8	12.2
8	a	..	27.1	26.5	26.4	26.5	26.4	26.0	26.0	25.5
	b	..	9.0	10.4	11.8	12.5	12.9	12.3	12.4	12.6
9	a	..	25.7	25.8	25.0	24.6	23.5	24.1	22.9	23.7
	b	..	12.5	13.3	14.0	15.2	15.9	16.1	16.5	16.3
10	a	..	33.9	33.8	32.8	34.2	34.1	33.8	32.9	33.1
	b	..	2.8	3.3	3.8	3.9	5.4	7.2	7.6	8.2
11	a	24.9	23.5	20.8	15.7	9.0	6.0	6.9	21.2	..

	b	5.4	8.5	12.0	16.1	18.6	20.4	8.0	..	..
12	a	28.0	27.6	25.1	27.1	27.5	27.9	27.2	26.7	25.9
	b	8.6	8.4	9.1	9.5	9.8	10.9	11.4	11.9	11.9
13	a	..	25.8	25.8	24.9	24.2	23.7	23.2	23.7	23.0
	b	..	11.5	13.0	13.4	14.9	15.4	15.7	15.8	16.6
14	a	..	25.2	23.7	20.7	17.8	13.7	10.6	10.9	11.3
	b	..	5.4	8.5	11.3	14.2	16.5	16.1	8.8	4.2
15	a	..	29.4	29.4	29.6	30.4	29.8	29.9	30.4	29.5
	b	..	0.6	0.9	1.4	2.0	2.5	3.0	2.7	2.4
16	a	..	27.4	25.7	24.1	22.5	21.1	20.1	19.9	19.0
	b	..	5.8	8.7	10.9	12.6	13.6	..	16.0	17.6
17	a	..	26.6	25.5	25.4	25.1	24.5	23.6	23.8	23.9
	b	..	9.1	11.8	13.4	15.9	16.6	16.4	16.8	16.5
18	a	32.3	26.7	24.7	23.3	21.0	18.2	16.7	14.2	12.7
	b	1.0	1.6	3.2	5.3	8.2	9.8	12.0	13.3	14.5
Sample No.		1270°	1300°	1325°	1350°	1375°	1400°	1425°	1450°	1475°
1	a	22.9	22.0	22.1	22.7	22.1	22.3	21.4	..	20.9
	b	17.3	17.2	..	..	..	..	..	..	..
2	a	26.9	25.7	25.9	26.3	26.4	26.1	25.8	..	25.1
	b	10.7	11.3	..	..	..	..	..	..	..
3	a	24.1	24.4	22.3	22.4	23.4	24.7	21.6	21.9	21.8
	b	11.1	9.9	..	..	..	..	..	..	..
4	a	..	..	..	..	..	..	..	..	..
	b	..	..	..	..	..	..	..	..	..
5	a	8.6	8.2	9.6	10.8	8.1	8.3	..	7.2	8.7
	b	6.2	..	..	..	..	..	..	..	..
6	a	16.8	..	..	..	..	..	..	..	..
	b	..	..	..	..	..	..	..	..	..
7	a	22.0	..	21.3	21.9	20.8	21.1	20.4	19.1	19.0
	b	11.6	..	..	..	..	..	..	..	..
8	a	24.4	24.6	22.1	23.8	23.3	23.4	23.4	..	22.5
	b	12.6	11.3	..	..	..	..	..	..	..
9	a	23.5	23.8	22.7	23.1	22.6	22.4	22.2	22.2	20.8
	b	15.9	15.0	..	..	..	..	..	..	..
10	a	33.1	32.4	32.7	32.0	32.0	33.7	32.6	..	33.4
	b	8.4	8.6	..	..	..	..	..	..	..
11	a	..	..	..	..	..	..	..	..	..
	b	..	..	..	..	..	..	..	..	..
12	a	..	26.5	27.3	27.8	27.2	26.9	26.3	26.1	24.0
	b	..	10.7	..	..	..	..	..	..	..
13	a	23.0	22.5	22.3	22.1	21.7	21.4	..	21.3	20.3
	b	16.6	16.6	..	..	..	..	..	..	..
14	a	12.1	..	..	..	..	..	..	..	..
	b	..	..	..	..	..	..	..	..	..
15	a	29.7	29.7	29.0	29.0	29.3	..	28.8	..	27.8
	b	0.9	0.3	..	..	..	..	..	..	..
16	a	18.4	18.3	14.6	14.8	14.6	13.3	12.0	..	9.7
	b	18.1	18.1	..	..	..	..	..	..	..
17	a	23.3	22.8	19.4	19.7	20.0	20.1	21.5	..	19.9
	b	15.8	14.2	..	..	..	..	..	..	..
18	a	11.1	..	5.3	2.9	2.3	3.1	5.3	3.8	1.6
	b	14.3	..	..	..	..	..	..	..	..

EFFECT OF TIME AND TEMPERATURE UPON THE CHLORINATION OF FLINT FIRE CLAY

BY HERBERT F. KRIEGE

ABSTRACT

An experiment is described in which flint fire clays were chlorinated at fixed temperatures between 500°C and 950°C and for varying periods of time. A replaceable condensing system permitted the rate of formation of the volatile chlorides to be studied.

It is a well-known practice to prepare the chlorides of many elements from their respective oxides by passing chlorine over these oxides heated to suitable temperatures in the presence of some reducing agent, as carbon. Recent literature reveals some efforts along theoretical lines¹ and quite a number of patents² pertaining to the chlorination of clays and some

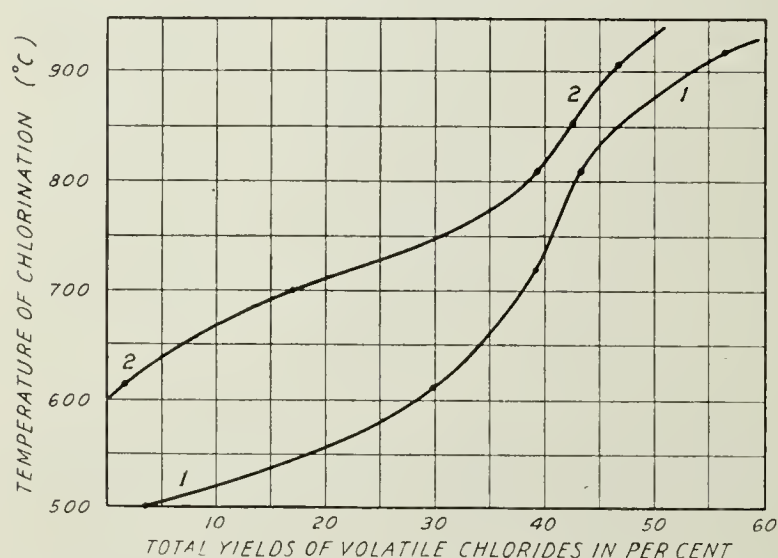


FIG. 1.—Abscissae, total yields of volatile chlorides in per cent; ordinates, temperatures of chlorination.

other silicates under the above conditions. The experiments in this paper deal with the partial chlorination of flint fire clays.

The two clays used in this experiment were taken from some pits near Warrenton, Mo. Both agreed fairly well with the composition of kaolinite, the total percentage of the oxides other than silica, alumina, and water being less than one-half per cent. Clay No. 1 contained some organic matter and was quite free from grittiness; clay No. 2 contained some free silica and was quite hard.

To prepare a charge for a run, the clay was ground to pass 100-mesh, boiled for one-half hour with a half normal solution of sulphuric acid to free it from the soluble impurities, then dried at 105°C for two hours. A weighed sample was then moistened and thoroughly mixed with the amount of lampblack theoretically necessary to reduce all the metallic oxides present in the clay. The lumpy mass was dried at 105°C, reground to pass 50-mesh and placed in the central portion of a silica combustion tube. Loosely fitting plugs of filter paper kept the charge in place until the run was started.

Heating of the charge was conducted in an electric resistance combustion furnace. With the aid of a pyrometer calibrations were made on the furnace before and during a run. Between the temperatures 450°C

¹ M. J. Barlot and Ed. Chauvenet, *Comptes Rendus*, **157**, 1153, etc.

² U. S. Pat., Weaver, 1,238,604; 1,217,471, etc.; German Patents, Siemens-Halske, 289,909; R. van Lieden, 267,876, etc.

and 970°C it was possible to control it to within 30°C. The chlorination products were collected in a condensing train attached to the combustion tube.

The chlorine was prepared by the action of concentrated hydrochloric acid upon a mixture of potassium permanganate and manganese dioxide. Such a flow of chlorine was maintained that the rate of evolution of the gas after passage over the charge and through the condensing system was approximately 0.15 liters per minute. The chlorine was dried by a fourteen inch calcium chloride tower. Some hydrogen chloride was probably in the gas stream, from the acid used in the chlorine generator, and from the combination of the chlorine with the water held chemically in the clay at temperatures below 450°C.

The diameter of the condensing system was nowhere less than two centimeters to prevent choking by the chlorides formed. By keeping various parts of the train at the following temperatures above 200°C, from 85° to 95°C, and below 18°C, it was hoped to effect a fairly complete separation of the volatile products into ferric chloride, aluminium chloride, and silicon tetrachloride, respectively. The 500-cc. flasks which served as receptacles for the various chlorides could be replaced by others during a run. The plan of separation was not very successful, so the products caught were combined and the analysis was made upon the whole. Using clay No. 1, quite a large amount of chlorides formed in the residual charge and collected in the tube during cooling, the flow of chlorine being maintained. These products were recovered by washing out the tube well with water, the wash being boiled for thirty minutes, filtered, and analyzed in the usual way. This is referred to in the tables under the heading "Water Soluble Residue." With clay No. 2 chlorine was not passed over the charge during cooling. The percentages given in the tables following are as oxides on the basis of the original sample of washed clay.

In order to insure uniform conditions, the temperature of the furnace was brought to the desired degree before the run of chlorine was begun. The moisture from the dehydration of the clay during the preliminary heating was removed as completely as possible by a gentle stream of air.

With the hope of obtaining some information on the rate of chlorination, the condensing system was replaced at three intervals during the run. In run E with clay No. 1, for example, the condensing system was replaced after chlorine had been passing through for 25 minutes which is called "period a;" the chlorination was then continued for 30 minutes (period b), when a third system was inserted and the run continued for 35 minutes more (period c). The amounts of products retained during each period were then determined, and the rate, expressed in per cent per minute, was calculated. The data obtained at the different temperatures are given in condensed form in the tables which follow.

TABLE I—CLAY NO. 1

	Run Temperature	A 500°C	B 605°C	C 715°C	D 810°C	E 915°C
	a	17 min.	17 min.	20 min.	20 min.	25 min.
Time	b	33 min.	33 min.	50 min.	30 min.	30 min.
	c	40 min.	40 min.	35 min.	40 min.	35 min.
Sample weight		4.0730g.	4.5913g.	4.8461g.	4.3397g.	4.7868g.
Total chlorination products, as oxides, in per cent		3.87	30.03	39.37	43.01	56.55
Yield during	in %	0.204	0.980	1.32	4.58	8.02
period "a"	% per min.	0.012	0.057	0.066	0.229	0.321
Yield during	in %	0.268	8.97	13.42	9.03	11.28
period "b"	% per min.	0.008	0.260	0.269	0.301	0.376
Yield during	in %	0.536	1.290	1.94	2.59	4.70
period "c"	% per min.	0.014	0.032	0.060	0.065	0.134
Water soluble residue in per cent (from tube)		2.86	18.79	22.69	26.81	32.55
Ratio of Al_2O_3 : SiO_2		....	2.46	2.45	2.40	2.37

TABLE II—CLAY NO. 2

	Run Temperature	A 505°C	B 610°C	C 700°C	D 805°C	E 850°C	F 910°C
	a	20 min.	25 min.	20 min.	20 min.	20 min.	22 min.
Time	b	30 min.	35 min.	30 min.	30 min.	30 min.	25 min.
	c	40 min.	lost	40 min.	40 min.	....	....
Sample weight		0.3359g.	0.7739g.	0.9605g.	2.5528g.	2.7467g.	2.5919g.
Total products as oxides in per cent		0.00	1.56	16.60	39.10	41.54	46.58
Yield							
during in %		0.00	0.49	2.95	3.46	12.18	20.65
period "a"	% per min.	0.00	0.02	0.148	0.173	0.609	0.939
Yield							
during in %		0.00	1.07	2.07	20.12	24.59	23.23
period "b"	% per min.	0.00	0.03	0.069	0.671	0.829	0.929
Yield							
during in %		0.00	lost	2.20	8.99	stopped	
period "c"	% per min.	0.00	lost	0.055	0.225	stopped	
Water soluble resi- due from combus- tion tube in per cent		0.00	0.00	9.38	6.53	4.77	2.70
Value of Al_2O_3 : SiO_2		....	....	1.66	1.55	1.23	1.27

It will be seen that the ratio of aluminium oxide to silicon dioxide chlorinated is greater than unity, as high as 2.46 in one run with clay No. 1, while in the original clay this ratio is approximately 0.85. In the German Patent of Siemens-Halske referred to before, it is claimed that fairly pure aluminium chloride can be obtained from a silicate by keep-

ing the amounts of carbon and chlorine low enough to react with the aluminium oxide only. While this was not attempted in this experiment, conditions affecting the clay in such a manner may have been introduced.

It is evident that the rate of chlorination of flint fire clay increases rapidly with the temperature. With one exception, run C in clay No. 2, the total yield of chlorides during the middle period "b" was greater than that in the last period "c," even though the latter was from ten to twenty-four minutes longer than the former. It is interesting to note the decrease, however slight, in the value of the aluminium oxide to silicon dioxide ratio with increase in temperature. Apparently temperature is also a factor in the selective reduction within the charge. That the yield during period "b" should have been greater than that during period "c" may have been due to changes in physical condition, such as surface exposure, etc., in the charge during the run.

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USE OF SEDIMENTARY KAOLINS OF GEORGIA IN WHITE-WARES¹

BY G. A. BOLE² AND R. T. STULL³

ABSTRACT

Introduction.—From twenty-six different clays tested the eleven best suited to the white ware industries were washed and, after preliminary tests were run, were tried out in the different whiteware industries.

Laboratory Tests on Crude Clays.—Tables containing data on the physical properties of the green and burned clays are given.

Laboratory Tests on Washed Clays.—Test bars and color pats were made from a typical whiteware body. The usual physical tests on unburned and burned bodies are reported. Results obtained on the rate of casting and strength of the clays as compared to English and Florida clays are included in the data.

Industrial Application.—Plant practice tests carried out at two floor tile and one wall tile plant are reported. Bodies containing eleven Georgia clays were tried out. Better results were obtained in the vitrified bodies than in the porous bodies. The smaller shapes gave better results than the larger. Tests on general ware and electrical porcelain are in progress. The conclusion is reached that the Georgia sedimentary clays can be used to displace all the china clay in a vitrified tile body but less than half the china clay in plastic bodies. The color of a body is greatly improved by using washed clay and can be further improved by the addition of cobalt stain.

Introduction

Considerable work has been done on the white clays of the lower Appalachian Region.⁴ The greater part of this work, however, pertains to the primary clays of the Piedmont Plateau. The work which has been done on the secondary clays of the coastal plain has been largely geological. The outstanding exception is the work of Sproat⁵ who made a survey of the mining and washing method used in the Dry Branch district of Georgia. After modifying the washing practice at the plant of the Georgia Kaolin Company to include the use of electrolytes to float the clay and after preliminary tests had been made on the washed clay the refined product was tested under factory practice in dry pressed ceramic bodies.

The work of Sproat in the Dry Branch district having proved of interest to the ceramic industries, it was evident that the availability and character of the sedimentary clays from a larger area should be investigated but in a manner considerably different from that followed by Sproat. A coöperative agreement between the Bureau and the Central of Georgia

¹ By permission Director, U. S. Bureau of Mines.

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⁴ "White Ware Clays East of Mississippi," Stull-Watts-Schurecht (in print). U. S. G. S., *Bull.* 708—H. Ries, W. S. Bayley and others. U. S. B. M., *Bull.* 53—A. S. Watts. Georgia State Geological Survey, *Bull.* 18—O. Veatch.

⁵ *Bull.* 128, U. S. Bur. Mines—Sproat.

Railway Company provided the occasion and necessary funds for an investigation of the coastal plain deposits lying within the State of Georgia. This deposit extends from Fort Gaines on the Chattahoochee River on the west, south of Macon in the center of the state, to Augusta on the Savannah River.

Twenty-six lots of one ton each were shipped from the leading operating mines and undeveloped prospects in this area. These samples included bauxites as well as bauxitic clays and kaolins. After preliminary laboratory investigations which eliminated those kaolins showing too much color as unsuitable for whiteware, the clays which gave promise of producing a whiteware body were washed in thousand pound lots in the whirlpool washer. Electrolyte was used to deflocculate and later to flocculate the clay. Results of the washing of the clays were published in a former paper of this series.¹

After the clays had been washed, laboratory tests were made leading to information that could be used in connection with the plant practice work which was later to be done.

This presentation (the third of the series) has to do with (a) the preliminary laboratory tests on the crude clays, (b) the laboratory work on the washed clays and (c) the plant practice investigation.

Preliminary Laboratory Tests on Crude Clays

Preliminary laboratory work on the crude clays consisted of making the customary physical tests which included: water of plasticity, drying and burning shrinkage, porosity, color and deformation temperature.

The clay was carefully sampled by quartering the ton sample to a thirty pound sample. This was disintegrated so as to pass a 40-mesh sieve and again thoroughly mixed. A pound of the clay thus prepared was saved for the chemical analysis.

Wet screen analyses were made. The screens used were Tyler standard No. 65, No. 100 and No. 150. Samples from the material on all the screens were saved for microscopic examination.

The material passing the No. 150 screen was made up into bars and disks which were tested to determine color, deformation, shrinkage, porosity, drying and burning behavior. The bars and pats were burned in two sets to cones 01 and 11. Results of these tests are shown in Table II.

The viscosity tests were made by determining the time required for 250 cc. of a 25% slip to flow through a given sized orifice in a Marriott tube after varying percentages of electrolyte had been added. The clay slip was blunged 12 hours before a determination was run. The electrolytes

¹ Stull and Bole, "Washing Tests of Georgia Clays," *Jour. Amer. Ceram. Soc.*, **6** [6], 730 (1923).

used were caustic soda and acetic acid. The results of these tests have been shown graphically.¹

The clays are classified (see Table I) according to their alumina content alone. A clay containing up to 40% of alumina is classed as a kaolin; the clays containing between 40 and 52% alumina are classed as bauxitic kaolins; and those containing more than 52% are classed as bauxites.

The data presented in Table II need no explanation with the exception of those in the column headed "color." These numbers represent the relative whiteness of the clays under test. The whitest burning clay (No. 1) represents the best of the Georgia clays. The poorest color (No. 10) was a decided brown.

TABLE I
SCREEN ANALYSIS

Clay	Kind of clay	On 65	On 100	On 150	Through 150
G-1	Kaolin	8.58	6.32	1.07	84.00
G-1b	"	.007	.003	.008	99.082
G-2	Bauxitic-kaolin	7.26	2.27	2.17	88.25
G-3	Kaolin	9.54	2.66	5.68	82.11
G-4	"	20.02	2.31	1.77	75.94
G-5	"	1.89	0.90	1.01	98.29
G-6	"	5.26	2.49	6.08	86.15
G-7	"	4.46	2.33	2.17	91.02
G-8	"	1.59	1.03	1.12	96.23
G-9	"	1.96	1.86	2.45	92.11
G-10	Bauxite	26.96	4.22	2.39	66.42
G-11	Kaolin	44.10	5.07	4.66	46.15
G-12	Bauxite	39.62	4.52	5.73	50.09
G-13	Bauxitic-kaolin	39.89	3.06	4.36	52.67
G-14	Bauxite	19.37	3.12	4.09	73.41
G-15	Kaolin	0.22	0.33	0.62	98.83
G-16	"	0.25	0.21	0.16	99.37
G-17	"	0.64	1.42	3.05	94.94
G-18	Bauxitic-kaolin	32.50	4.18	6.96	56.34
G-19	Kaolin	8.08	3.74	2.55	85.44
G-20	Bauxitic-Kaolin	10.38	3.07	3.02	73.51
G-21	Kaolin	0.20	0.14	0.43	99.23
G-22	"	0.45	0.34	0.13	99.07
G-23	"	1.88	1.41	2.43	94.76
G-24	"	1.12	1.29	0.61	96.96
G-26	"	.006	.01	.04	99.89

Laboratory Work on Washed Georgia Clays

It was evident from the preliminary tests on the crude clays that many of the kaolins could not be freed from iron and titania so as to be useful in the whiteware industry because the impurity was present as a stain

¹ Stull and Bole, *loc. cit.*

TABLE II

WORKING PROPERTIES AND FIRE TESTS ON GEORGIA CLAYS

CLAY	% H ₂ O plas- ticity	CRUDE	Drying behav- ior	% Vol. shrink- age	CONE 01			% Vol. shrinkage	CONE 11		Deform- ation cone.
		% Vol. shrink- age			% Poros- ity	Burning behav- ior	Color No.		% Poros- ity	Color No.	
G-1	41.06	24.83	Good	20.54	35.75	Good	3	40.05	29.20	8	34
G-1b	31.20	20.60	Good	20.90	39.20	Fair	2	44.30	16.50	8	34
G-2	31.76	11.56	Poor	13.83	50.71	Poor	1	25.40	41.25	2	34
G-3	35.76	17.05	Fair	19.98	38.39	Fair	3	42.64	14.07	7	34
G-4	33.60	15.40	Fair	11.76	42.81	Fair	1	35.04	24.41	2	34
G-5	38.50	22.68	Good	13.01	41.37	Good	2	38.01	22.82	3	34 ¹ / ₂
G-6	44.50	24.97	Fair	14.34	43.47	Poor	2	47.27	12.65	3	34
G-7	35.20	18.71	Good	18.10	40.81	Fair	2	41.88	13.62	5	35
G-8	42.33	28.19	Good	14.46	40.14	Good	3	35.59	16.37	6	34
G-9	38.06	27.40	Good	14.68	42.79	Good	2	69.07	24.48	5	34
G-10	28.60	11.03	Poor	12.06	54.15	Fair	2	44.77	27.77	6	38
G-11	39.66	20.38	Poor	18.36	42.52	Good	3	43.09	24.30	8	35
G-12	29.68	14.49	Poor	13.52	56.24	Good	3	47.10	29.56	7	39
G-13	32.80	7.53	Bad	16.80	49.10	Good	3	45.15	27.05	7	37 ¹ / ₂
G-14	33.83	12.90	Poor	12.80	36.60	Poor	2	47.87	29.46	4	39
G-15	38.73	15.83	Fair	14.68	44.20	Good	1	37.32	25.72	2	34 ¹ / ₂
G-16	43.30	20.90	Fair	12.69	46.20	Good	1	36.43	26.96	3	34
G-17	41.90	17.04	Good	12.17	46.44	Fair	2	34.40	28.55	4	33
G-18	28.96	14.21	Poor	16.96	50.20	Poor	7	55.32	24.00	10	34
G-19	42.40	13.34	Bad	bars cracked		Bad	3	52.17	15.51	7	34 ¹ / ₂
G-20	30.13	11.32	Good	15.20	48.60	Poor	3	44.86	15.93	6	36
G-21	49.50	36.46	Poor	25.09	40.83	Bad	3	44.57	13.94	9	34
G-22	38.33	16.55	Fair	bars cracked		Bad	2	36.65	11.94	6	34
G-23	38.10	26.66	Fair	12.61	38.83	Good	2	32.09	15.03	7	33
G-24	38.23	20.66	Good	15.58	42.00	Good	1	45.04	14.92	2	34
G-26	28.60	16.80	Good	14.60	45.80	Good	1	35.80	23.80	3	34

or was so finely divided that it could not be removed by an elutriation process. Some of these clays after washing when fired to cone 01 gave a good color but when fired to a temperature used in the whiteware industries developed a decided cream tinge. Many of the clays which do not burn to a good white were of excellent color in the crude and will be tested for filler purposes.

The clays which gave especial promise as whiteware clays were the following: G-1b, G-2, G-4, G-7, G-15, G-16, G-24, and G-26.

In order to try out the speed of casting of the Georgia clays in comparison with a body containing English clays a series of tests were made in which cups were cast in a plaster mold and the weight of the cups after drying recorded. The data obtained on the Georgia clays together with a similar body containing English and Florida clays are given in Table III. The clays were all made up with sufficient electrolyte (50% Na₂SiO₂—50% Na₂CO₃) to produce maximum fluidity in a 40% body—60% water mix. The body mixes were the same as those used in the other tests.

Practically all the cups, except those containing the English clay, cracked upon drying.

TABLE III

WORKING PROPERTIES AND FIRE TESTS ON BODY CONTAINING GEORGIA CLAY
The test body on which the tests were run using the washed clays was the following:

Feldspar	25	Per cent
Flint	25	" "
Ball Clay	5	" "
Test Clay	45	" "
	100	" "

	Water of plasticity	Drying shrinkage (vol.)	Casting wt. of cup	Cross breaking strength, lbs. sq. in.	Porosity	CONE 5½ Shrinkage vol.	Color	Porosity	CONE 12 Shrinkage vol.	Color
G-1b	25.2	13.2	65.2	8.2	16.3	22.1	3	2.30	28.8	3
G-2	25.8	7.17	70.1	7.4	20.4	24.0	2	6.39	30.9	3
G-4	24.8	12.16	60.1	11.3	14.5	21.3	2	2.80	31.6	2
G-7	26.3	15.37	63.5	10.8	15.4	23.8	4	.32	28.0	4
G-15	28.5	21.55	64.2	10.2	16.7	21.3	2	2.33	28.9	3
G-16	28.4	18.20	63.1	9.4	20.5	20.6	3	3.68	28.6	3
G-24	27.2	17.82	65.2	15.6	14.2	23.2	4	.11	30.9	4
G-26	26.0	14.80	68.1	12.0	16.4	22.4	3	2.12	29.4	3
E			62.5	8.9						
F			46.9	23.6						

Cross breaking strength tests on solid bars made by pouring the slip into a 1" x 1" x 6" mold were made. Results given in Table III represent the number of pounds necessary to break one of these bars at the center, the bar being supported on a 5" span by knife edges.

The Plant Practice Tests

General Ware and Electrical Insulators.—Commercial tests of several of the clays are being made. About five hundred pounds of the clays G-2 and G-15 (washed) were sent to a pottery in the East Liverpool district to be made into tableware. The body into which it was to be incorporated is a semi-porcelain. The body will be made up into three hundred pieces of ware in the ordinary plant procedure; some will be cast, others jiggered, and all then dried, burned, glazed and decorated in the regular way.

One hundred pounds of a high tension electrical porcelain body was prepared at the Columbus Station of the Bureau of Mines, consisting of feldspar, 19.25; whiting, 2.26; flint, 38.60; ball clay, 20.00; test kaolin, 20.00; and sent to a plant at East Liverpool where it will be made up into insulators by the semi-dry press process and tested for di-electric strength. The body mix was as follows:

The plant tests have as their aim the gathering of reliable data on the adaptability of the Georgia sedimentary clays to the plastic and dry press processes. Due to the fact that the potters' strike seriously interrupted production at the time and due later to the urgent demand for quantity production the results of the tests are not yet at hand. A complete report on the tableware and electrical porcelain tests will appear later.

Wall and Floor Tile.—Several of the clays were run through plant practice in floor and wall tile bodies at Zanesville, Ohio, and Olean, New York. Clays G-2, G-4, G-7, G-15, and G-16 were used in floor tile and G-2, G-7 and G-16 were tried out in wall tile bodies.

As a preliminary survey the body compositions first tried in wall tile were as follows:

	(1)	(2)
Cornwall Stone (Eureka).....	12.0	....
Tenn. Ball Clay No. 7.....	12.0	8.0
Cooley Ball Clay.....	12.0	8.0
Clay (Experimental).....	30.0	36.0
Flint.....	34.0	36.0
Feldspar.....	....	12.0
	<hr/> 100.0	<hr/> 100.0

Seventy-five pound batches of these bodies were blunged for four hours and screened through a No. 140 screen. The slip was continuously agitated until it was run into the presses where it was subjected to a pressure of 90 pounds. All the bodies filtered easily and formed good firm cakes. The cakes were dried and pulverized to pass 40 mesh.

The tile were made in two sizes, 6" x 6" x $15/32$ " and 6" x 3" x $3/8$ ", under a pressure of 50 pounds per square inch in a steam press. The bodies containing G-7 and G-16 pressed very well and no loss occurred in the handling and trimming, but the body containing G-2 was very weak and broke easily in the "green" state. The moisture content for all the bodies was approximately nine per cent.

The tile were air dried and fired in up-draft kilns to cone 11 to 12 which were placed inside the saggers.

The 6" x 6" tiles received a temperature treatment corresponding to the deformation of cone 11, while the 3" x 6" tiles were fired to cone 12. The bisque was then dipped in a clear glaze and fired to cone 1.

All of the tile fired satisfactorily but the 6" x 6" size cracked badly during the bisque fire. No additional cracks developed during the glost burn. The large shapes made from the body containing G-2 behaved particularly badly in the bisque burn. This is a peculiar clay which seems to have the working properties of a kaolin, but is above the kaolinite ratio in alumina.

When the data had been examined it was found that these clays varied widely in degree of vitrification and consequently in shrinkage and porosity at cone 11. It was therefore decided to blend the clays in an endeavor to get a body with approximately the shrinkage and porosity desired in the industry, *i. e.*, 13% absorption and not more than 5% shrinkage at cone 11.

The percentage of ball clay was lowered in the second set of tests as the Georgia clays are themselves quite plastic. The flint was raised in three cases somewhat in an endeavor to open up the body. Furthermore, the second set of trial bodies was more thoroughly blunged than was the first set. In no case, however, was time allowed for the moisture thoroughly to permeate the dried powder prior to pressing.

The bodies used for the second set of tests were as follows:

COMPOSITION						
	(1)	(2)	(3)	(4)	(5)	(6)
Feldspar.....	12.0	12.0	12.0	12.0	12.0	12.0
Tenn. Ball Clay						
No. 7.....	8.0	8.0	8.0	7.0	7.0	7.0
Cooley Ball Clay	8.0	8.0	8.0	7.0	7.0	7.0
Clay (Experi-						
mental).....	G-7 36.0	G-7 18.0	G-7 27.0	G-7 36.0	G-7 18.0	G-7 27.0
		G-16 18.0	G-2 9.0		G-16 18.0	G-2 9.0
Flint.....	36.0	36.0	36.0	38.0	38.0	38.0
	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>	<hr/>
	100.0	100.0	100.0	100.0	100.0	100.0

PHYSICAL PROPERTIES						
	(1)	(2)	(3)	(4)	(5)	(6)
Shrinkage (linear).....	7.0	5.6	5.0	6.8	5.5	4.8
Absorption.....	11.7	9.2	13.0	11.7	10.5	15.8
Color.....	C	A	B	C	A	A

The bodies used in the second set of tests were prepared and pressed in the same way as in the first with the exceptions already noted.

The bodies worked equally as well as in the first tests and developed no cracks during drying. When the ware had been drawn from the bisque kiln it was found that the cracking had been decreased, but not eliminated, especially in the case of the larger pieces.

As the dies used were made with allowance of 4% shrinkage, the tiles made from the Georgia clay were all under size. The commercial ware was fired (cone 11) to 13% absorption, hence body No. 3 had approximately the desired absorption and not an excessive shrinkage. The 6" x 3" tile of this composition passed the plant test 80% perfect; the 6" x 6" went through 40% perfect.

The plant tests on wall tile were then discontinued. Later tests at the Station indicated that, by blending the clays in the proper ratio and using the blend to less than 20% kaolin in a body already containing 15% of a primary kaolin, good results can be expected. Such a body is to be tested under plant practice in the near future.

Conclusions on Wall Tile Tests.—The tile in no case showed a tendency to warp. There were no specks visible in any of the specimens except those introduced by tramp iron, this indicates that the cyclone washing was effective in eliminating a serious objection raised against Georgia kaolins.

The color of the glazed ware made from the different clays was, in order of whiteness, G-2, G-16 and G-7. The color of the tile made from G-2 and G-16 while not as chalk white as one or two of the commercial makes (which may have contained blue stain) is, nevertheless, in every sense of the word good whiteware. The tile made from G-7 had a slight ivory tinge but was as good a white as several of the commercial wares. No blue stain was used in the trial bodies.

About 20% of properly blended mix of the Georgia sedimentary kaolins can doubtless be used in wall tile bodies, but inasmuch as these kaolins are almost lacking in free silica, the flint should be increased accordingly.

The sedimentary kaolins as prepared by Sproat¹ were tested under plant practice in the wall and floor tile industries where they are reported to have given satisfactory results.

Floor Tile.—Two floor tile bodies were tested under regular plant practice. Body (A) was prepared in the same manner as were the first wall tile bodies. Body (B) was weighed and ground wet in a test mill, after which it was filter pressed. From this point on the process was identical with the regular plant practice.

Five clays in all were tested. Three in body (A): G-2, G-7 and G-16; and two in body (B): G-4 and G-15.

Compositions of the vitreous floor tile bodies were:

BODY A		BODY B	
Erwin Feldspar.....	45	Feldspar.....	40
Flint.....	15	Flint.....	20
Clay (Experimental).....	30	Clay (Experimental)...	30
Kentucky Ball Clay No. 4.....	10	Tenn. Ball Clay.....	10
		Heavy MgO.....	1

Body (A) was molded in two sizes—one inch hexagons and $2\frac{1}{6}$ " x $2\frac{1}{8}$ " x $\frac{1}{2}$ " shapes. The dust was pressed in hydraulic presses under a pressure of 2000 and 1600 pounds, respectively. No loss occurred due to handling or trimming. Body (B) was pressed into shapes $\frac{1}{2}$ " x 1" x $\frac{1}{2}$ ".

¹ Sproat, *loc. cit.*

The tile made from body (A) was air dried and burned in saggars to cone 12 in an up-draft kiln. The ware came from the kiln in perfect condition. There were no losses from warping or cracking. The tiles with G-7 and G-16 showed greater vitrification than did the regular body and the color with these was not quite so good as that of the regular ware. G-2 body was very white and compared favorably with the regular product. All tile made from the different bodies showed zero absorption.

The results on G-4 and G-15 made into body (B) following the same practice as was used in the manufacture of body (A), from the point where the dust was pressed, gave even better results as they were burned to cone 10 to 11 instead of cone 12. The color was somewhat better than that of tile made from G-7 and G-16. They were also whiter than the regular commercial ware made at the plant. The surface finish was not so good, however, as the commercial ware due, no doubt, to the fact that the body was prepared in small batches and not as well granulated as the regular body prepared mechanically in large batches. Some of the commercial body was also prepared in the same manner and put through the process in every way to correspond to the bodies under test. The commercial body lacked the gloss which it has when prepared in the regular way. Both the floor tile bodies made from Georgia clay were whiter than the commercial bodies so made.

There was no loss in the floor tile bodies made from the Georgia clays due to drying or burning at either plant. All five clays are well suited to use in vitrified tile manufacture.

Discussion of Results

The use of Georgia (sedimentary) kaolins in the several whiteware industries is no novelty. They have been used in practically every type of pottery body, both dry press and plastic, where a china clay is required. In some cases they have been used very successfully while in others their use has been discontinued due to various reasons more or less warranted.

Their use has been abandoned by some chinaware manufacturers principally because of lack of uniformity. Many of the clays burn to a good white, while many others which burn to a cream color could be produced white enough to meet requirements if the proper care were taken in their mining and refining. However, some of the clays are so stained with colloidal iron oxide that their color cannot be improved by washing. Bleinger states that the slight variation from white shown by these clays can be corrected by the use of cobalt stain. The bulk of the Georgia clays are produced for the filler trade where whiteness in the raw state is all important and the burning color is of no consequence. A more serious effort should be put forth by the producers to cater primarily to the pot-

tery trade by producing in quantities, uniform as to color and working properties.

These clays have been used quite extensively in the sanitary tile and electrical porcelain industries. Some manufacturers have not used Georgia sedimentary kaolins in these wares because in the trials made, black specks developed during the firing. The tests just completed on clays washed at the Ceramic Station prove that the latter difficulty can be overcome by proper washing.

A serious problem in connection with the use of sedimentary clays is probably the high bisque loss and excessive shrinkage. These difficulties can, it seems, be overcome by proper body mixes and by the blending of the clays. These clays analyze close to theoretical kaolinite in alumina and silica. They, therefore, contain almost no free silica and bodies containing them require a higher flint content than bodies containing primary kaolins. A higher flint content improves whiteness.

Georgia clays, as pointed out many times, are very different from English clays in physical structure and to a less extent in mineralogical constitution, hence cannot be expected simply to displace the English clay in a ceramic body. It is a peculiar fact that no one ever suggests substituting entirely Florida for English clay, but to the writers' knowledge Georgia clays have been condemned in many cases because they will not substitute pound for pound in a plastic body for the imported clay. Florida clays have been used judiciously and have gained a reputation for possessing two very desirable qualities, namely: workability and strength. On the other hand they do not cast so rapidly as do the best Georgia or English clays. The more desirable Georgia clays cast as rapidly as do the English china clays and improve the workability of the mix nearly as well as do the Florida kaolins.

Conclusions

As indicated by tests made in two commercial plants, washed Georgia clays can be used to advantage to displace all of the English china clay in a vitrified dry press body of small size such as floor tile.

The washed clay can be used to displace a portion of the china clay in a porous dry press body such as wall tile up to about 20% of the batch. However, the extent to which the displacement may safely be carried depends largely upon the shape and size of the ware.

The amount of the sedimentary clays that can be used in plastic bodies is much less than in a press body and should probably not exceed 10 to 15% of the batch. The amount will vary with the ware being manufactured.

The proper blending of the clays together with judicious body mixes will render the Georgia clays much more available for whiteware purposes.

An increase in flint in bodies containing Georgia clays is essential to obviate crazing of the glaze, reduce shrinkage and incidentally to improve whiteness.

The color of ware made from a properly washed clay is about equal to the usual grade of china clay and it is only slightly inferior to the highest grade of English clay and domestic primary kaolins.

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ORIGINAL PAPERS

FURTHER STUDIES ON CAST GLASS POTS

BY R. F. GELLER¹ AND A. N. FINN

ABSTRACT

This paper is a progress report covering the work done by the Bureau of Standards during the past three years on the problem of cast glass pots. The work done is essentially an application of the results of research reported in previous Bureau publications and contains data on body compositions, the arching of pots and their resistance to optical glass. The following conclusions were made: (a) The casting of porcelain glass pots has passed the experimental stage; (b) The content of plastic clay is not of prime importance as long as the body will cast satisfactorily; (c) Proper watersmoking practically eliminates fissures and surface cracks; (d) Pots should be arched to the highest temperature consistent with the refractoriness of the body.

The present paper is essentially a progress report of investigations on the problem of cast porcelain glass pots, continued during the past three years by the Bureau of Standards. Previous publications of the Bureau² on this subject have covered in a comprehensive manner the results of generally accepted physical tests on various compositions, and also detailed procedures for casting. The laboratory results have been of great value in formulating desirable bodies, and the method for casting, as originally suggested, has remained unchanged except for engineering details.

¹ Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

² F. H. Riddle, *Jour. Amer. Ceram. Soc.*, 2 [8], 647 (1919); J. W. Wright and D. H. Fuller, *ibid.*, 2 [8], 659 (1919); D. H. Fuller, *ibid.*, 3 [7], 569 (1920).

It was felt, however, that the investigation required the application of the data obtained. The opportunity to do this is found in the Bureau itself where the history of the pot can be recorded by technically trained observers from the mixing of the raw batch to the breaking away of the pot shell from the finished glass.

The casting apparatus which has been installed in the Laboratory of the Industrial Building (see Fig. 1) has a capacity of three pots daily and is practically the same as that suggested in a previous publication¹ of the Bureau.

Body 332, as given in Table I, is the same as body number 6 of the

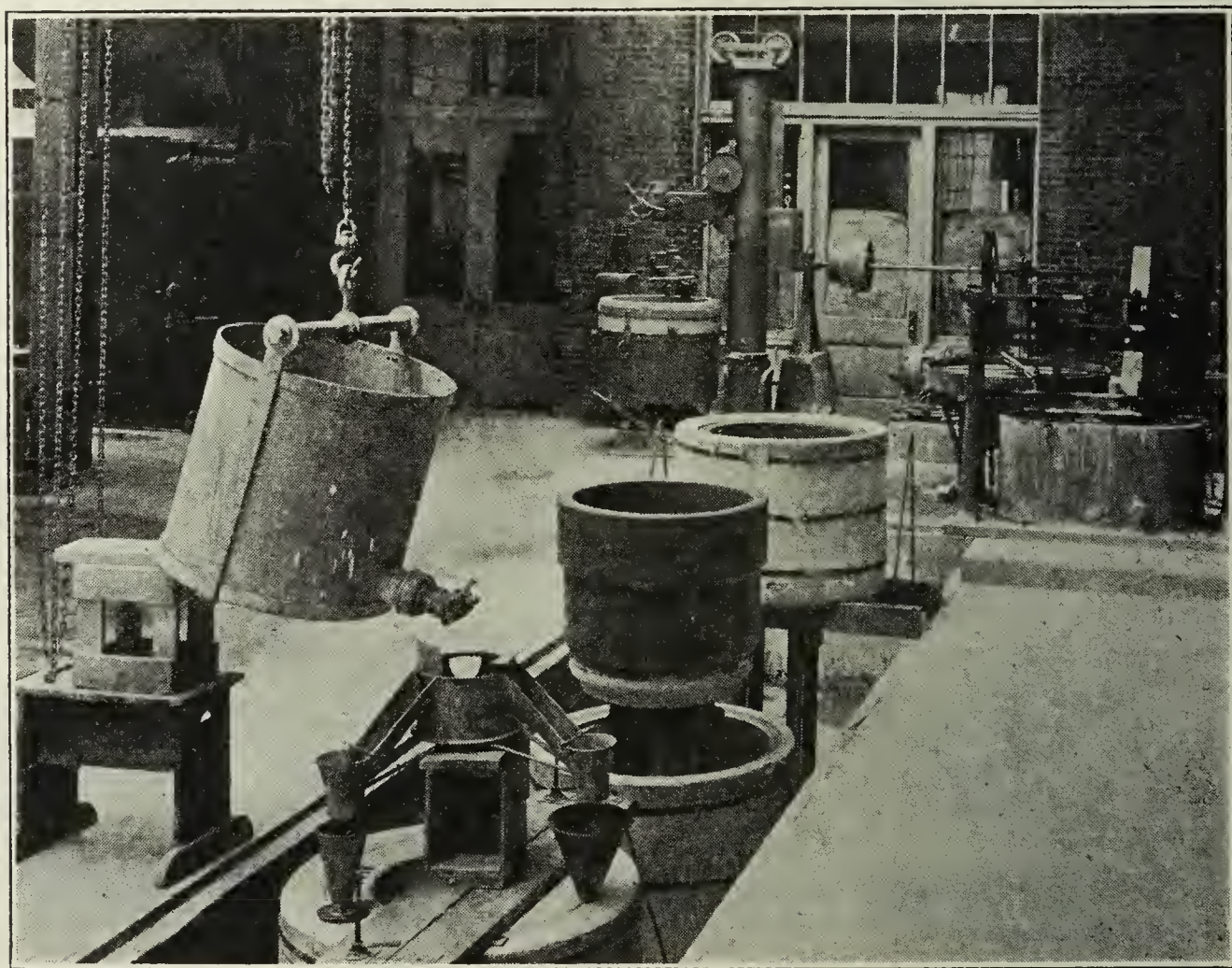


FIG. 1.

paper by D. H. Fuller. This body was one having desirable qualities as evidenced by laboratory tests, and was largely used in the work covered by this report.

As is evident from the table, bodies 332, 334 and 6 of this paper are essentially the same, the only variation being found in the composition of the grog. Body D was designed to produce a dense structure by means of a higher ball clay and fine grog content rather than with feldspar and bodies A and B were designed to study the effect of eliminating kaolin from the bond.

¹ F. H. Riddle, *loc. cit.*

TABLE I

	BODY COMPOSITIONS					
	332			Body Number		
	%	334	6	A	B	D
		%	%	%	%	%
Feldspar	6	6	6	2	2	4
Tenn. ball clay No. 5	10	10	10	35	35	16
Ky. ball clay No. 4	10	10	10	7	7	9
N. C. kaolin	12.5	12.5	12.5	..	..	12
Del. kaolin	4.5	4.5	4.5	..	..	4.5
Ga. kaolin	4.5	4.5	4.5	..	..	4.5
Flint	..	..	..	24	24	..
Grog	52.5	52.5	52.5	32	32	50

GROG COMPOSITIONS					
Tenn. ball clay		{ 19 ¹	{ 50 ¹	{ 50 ¹	{ 35 ¹
N. C. kaolin		{ 19	{ 50	{ 50	{ 35
Whiteware bisque	100	62	..	..	30

GROG SIZING					
10 to 20-mesh	35	35	35	35	20
20 to 40-mesh	45	45	45	45	50
Through 40-mesh	20	20	20	20	30

¹ Calcined to cone 10.

The deflocculating agent generally used in casting the pots consisted of sodium carbonate and sodium silicate. The carbonate varied from 0 to 80 parts per 100 parts of silicate. Excellent casts were also obtained by means of sodium silicate, sodium carbonate and gallic acid in the ratios of 100:8:8. This ratio could be varied to 76:8:32 without apparently affecting the casting properties, but as the gallic acid was increased above this amount the slip gradually became lifeless and would not cast successfully. The total amount of deflocculating agent used varied from 0.15% to 0.21% of the dry weight of the batch, the amount depending on the per cent of plastic material in the body.

The deflocculating agent is added to the water in the blunger before the clay is introduced and, after thoroughly blunging the entire batch, the quality of the slip is judged by its "feel." That is, the laborer in direct charge can tell after a little experience approximately how much additional water to use by the way the slip runs off his fingers. His observation is then checked by determining the specific gravity of a sample. The blunger is usually charged about 8:30 A.M. and the blunging continued until 3:30 P.M. when the slip is ready for casting. The core is withdrawn at 8:00 A.M. the following morning and twenty-four to thirty hours later the shell is lowered away from the pot. It is then ready for "slicking," after which it is carefully dried. The pot is then placed in a pot arch

TABLE II

Pot number	Body number	Melt number	Sp. gr. of slip	Max. temp. °C	Arching at max. temp. (in hours)	Type of glass	Remarks
15	334	424	1.94	1300	5	Boro-silicate	Bottom badly fissured
16	334	425	1.94	1300	5	Boro-silicate	Bottom badly fissured
17	334	426	1.93	1300	5	Boro-silicate	Pot O. K.
20	334	428	1.92	1300	5	Lt. Barium Crown	Leaked through a small hole. Probably a casting flaw
24	334	429	1.92	1300	5	Lt. Barium Crown	Pot O. K.
26	332	433	1.91	1300	5	Lt. Barium Crown	Small cracks
27	332	435	1.92	1300	5	Boro-silicate	Bottom fissured
29	332	434	1.92	1300	5	Lt. Barium Crown	Pot leaked
30	332	...	....	....	..	....	Cracked in arching
31	332	436	1.92	1300	5	Lt. Barium Crown	Bottom fissured
32	332	445	1.93	1300	5	Boro-silicate	Pot O. K.
33	332	438	1.92	1300	5	Barium Flint	Bottom fissured
34	332	437	1.93	1300	5	Medium Flint	Bottom fissured
37	332	441	1.92	1300	5	D. Barium Crown	Leaked badly. Compare with Pots 55 and 76
39	332	443	1.92	1300	8	Boro-silicate	Bottom fissured
41	332	446	1.90	1300	10	Boro-silicate	Pot O. K.
49	332	454	....	1300	8.5	Medium Flint	Porosity: side, 19.4; bottom 20.9
50	332	455	....	1260	10	Boro-silicate	Porosity: side, 19.0; bottom 21.2
51	332	456	....	1350	12	Medium Flint	Porosity: side, 16.4; bottom 18.3
52	332	459	....	1400	5	Lt. Barium Crown	Glass attack 1/4" in bottom. Porosity: 16.7%
53	332	457	....	1350	8	Medium Flint	

TABLE II (Continued)

54	332	458	....	1400	8	Medium Flint	Pot O. K. Porosity: 11.6%
55	332	460	....	1400	8	D. Barium Crown	Shows glass attack along fissures
58	332	464	....	1435	3	Dense Flint (1.65)	Pot leaked
61	332	466	....	1450	6	Boro-silicate	Pot bottom buckled due to high arching temperature. Porosity 11.2%
62	332	465	....	1450	6	Dense Flint	Pot O. K.
64	332	469	....	1400	8.5	Boro-silicate	Cracked during cooling
65	332	472	....	1400	6.5	Boro-silicate	Same as Pot 64
68	332	474	....	1425	7	L. Barium Crown	Pot O. K.
69	332	475	....	1425	7.5	Medium Flint	Pot O. K.
70	332	467	....	1450	4.5	Dense Flint	Bottom of pot buckled slightly due to high temp. O. K. Porosity 12.2%
72	332	468	....	1450	2	Medium Flint	Gallic acid used in casting. Pot O. K. Porosity 9.4%
73	332	477	....	1430	1	Boro-silicate	Pot O. K.
74	6	478	....	1425	8	Light Crown (soda lime)	Pot O. K.
75	6	479	....	1425	8	Boro-silicate	Pot O. K.
76	A	480	1.81	1425	16	D. Barium Crown	Slight penetration
77	A	481	1.85	1425	8	Boro-silicate	Pot O. K.
78	B	482	....	1425	8	Very Dense Flint	Slight penetration
80	B	483	....	1425	8	Light Crown	Pot O. K.
83	6	485	1.87	1425	9	Light Crown	Pot O. K.
84	6	486	1.90	1425	7	Boro-silicate	Pot O. K.
85	D	487	1.88	1425	17	Light Crown	Pot O. K.
87	D	488	....	1425	8	Boro-silicate	Pot O. K.

resting on 3 brick piers to permit a free circulation of furnace gases around it. According to present practice it is heated very slowly to 300°C and at an increased rate to 1425°C, as per the following schedule:

- 12 hours at 75°
- 12 hours at 100°
- 3 hours from 100–150—hold 9 hours
- 3 hours from 150–200—hold 9 hours
- 3 hours from 200–250—hold 9 hours
- 3 hours from 250–300—hold 9 hours
- 35 hours from 300–825 (15° per hr.)
- 24 hours from 825–1425 (25° per hr.)
- 8 hours at 1425°

When the burning is completed the pot is transferred from the pot arch to the hot melting furnace.

The temperature in the pot arch is measured by means of a thermocouple introduced through the crown. The couple is protected by means of a sillimanite tube of sufficient length to bring the end of the couple about 6 inches inside the furnace.

Approximately one hundred pots have been cast by the method outlined above and no failures have occurred except those resulting from the use of a mold which is too dry or a body of modified composition. The first cause of failure, due apparently to unequal or too rapid absorption of water from the slip, is usually overcome by one cast. The trouble may be caused either by a new mold or by an old mold which has not been used for some time. Preliminary wetting of the mold seems to result in unequal absorption of water by the plaster. In either case the pot develops serious cracks while in the mold. The second cause of failure is not serious and one cast is sufficient to determine the proper amount of deflocculating agent and water; or, as is sometimes the case, to determine whether or not the body is of proper composition to form a slip which will cast at all.

Table II contains, in abridged form, a summary of observations on forty-four pots cast and used by the Ceramic Division in the manufacture of optical glass. Data on twenty other pots, used in the making of borosilicate glass, is omitted since they were satisfactory in every way although small surface cracks had developed in the bottoms during the burning.

As is evident from the table, pots 15 to 49 inclusive were practically of the same composition and since they were burned in the same way, the only variable introduced is the type of glass used. It is to be noted that only the barium crown glasses (see pots 20, 29 and 37) caused serious trouble. In every other melt of this group the pots were quite satisfactory but not entirely so, because in no case can it be said that they were free from attack. In many cases the structure of the pot was fissured and showed well defined laminations which acted as lines of least resistance

for the glass attack. The porosities determined on specimens of pot 49, after the melt, are probably typical of this group.

The second group, from numbers 50 to 73 inclusive, were burned in the pot arches at the slower rate previously outlined, and to higher temperatures. The effect of higher arching on the final porosity is evident from the following:

Pot no.	Max. temp.	Time held	Mean porosity
49	1300	8.5	20.1
50	1260	10.0	20.1
51	1350	12.0	17.3
53	1350	8.0	16.7
54	1400	8.0	11.6
61	1450	6.0	11.2
70	1450	4.5	12.2
72	1450	2.0	9.4

There was also a very evident improvement in the structure of the pots and their resistance to glass attack. The body is denser, as evidenced by the decrease in porosity, and the tendency to form fissures is practically eliminated.

Results indicate that the best burning can be obtained in a pot arch, and the generally accepted procedure of burning pots in the melting furnace or of arching to 800–1000°C and then finishing the burn in the melting furnace, is not satisfactory since such treatment cannot burn the pot bottom thoroughly.

Pot 55 was the only exception noted. Pot 53 showed appreciable glass attack, but it had a fairly high porosity due to the low arching temperature. Melt 464 (pot 58) was blocked¹ repeatedly and it is possible that this treatment exaggerated an incipient strain in the pot which resulted in the leak.

It was evident from observations on the pots that the body of which they are composed is not sufficiently refractory to stand a temperature above 1435°C for any length of time in the pot arch, without more or less deformation. The buckling was noted on the bottoms of the pots at the three points of support.

In the last group of melts there are two main variables to be considered—the pot composition and the type of glass. The dense barium crown, and a very dense flint glass (see pots 76 and 78) penetrated the pot body

¹ Blocking consists of forcing a small amount of ammonium nitrate on the end of an iron rod through the glass to the bottom of the pot. The nitrate explodes almost immediately, stirring up the glass, and the force of such repeated explosions, especially under a glass of high density, may be sufficient to weaken the pot. Blocking is especially desirable in glasses containing lead oxide which is exceedingly corrosive and which, on account of its low melting point and high density tends to segregate at the bottom of the pot.

slightly. The balance of the pots were to all appearances perfect in their resistance to corrosion and fissuring. Bodies A and B are particularly worthy of note because their composition varied radically from any tried heretofore, but this variation in composition did not affect the resistance to glass attack. They did shrink excessively in burning, which was to be expected because of the high ball clay content. Body A for example, carried a total of 67% ball clay of which 25% was introduced in the grog and 42% in the bond. Four high ball clay pots have been used to date, all of which were very satisfactory regardless of the fact that two of them were used for the most corrosive glasses.

The work of the past three years on cast porcelain pots for optical glass seems to justify the following conclusions.

1. The casting of porcelain pots has passed the experimental stage and has become a matter of plant routine requiring very little if any technical control.
2. The ball clay and kaolin content is not a vital factor as long as the slip will cast properly and form a body of dense and homogeneous structure.
3. Slow burning to about 300° practically eliminates fissures and surface cracks.
4. Pots should be arched to the highest temperature consistent with the refractoriness of the body.

SOME CAUSES OF BLISTERING OF SHEET STEEL METAL ENAMELS¹

BY GEORGE F. COMSTOCK

ABSTRACT

This paper gives the results of a metallographic investigation of some samples of defective white enameled ware, the peculiarities of the steel underlying the defects having been examined through the microscope. Two distinct kinds of defects were recognized, one of which, characterized by dark spots arranged in streaks, was found to be due to foreign inclusions in the steel. It was concluded that the other defect, consisting of irregularly scattered spots, was most probably due to gas absorption during pickling, the ultimate cause lying either with the pickling process or the steel quality. Detailed descriptions and photomicrographs are given of the structures and inclusions in the steel bases of the samples examined.

Through the kindness of B. T. Sweely, Chairman of the Enamel Division of the AMERICAN CERAMIC SOCIETY, the author had an opportunity to study with his microscope the structural peculiarities of the steel under-



FIG. 1.—Natural size view of side of tea-kettle Sample 6, showing defective upper part with streaks of dark spots, and good lower part without spots.

lying certain defects on white enameled ware. The results of this study, on eight samples of ware, representing two distinct types of defect, are reported in this paper.

The nature of the defects studied is illustrated by Figs. 1 and 2. All consisted of black spots in the white enamel, the spots varying from mere discolorations to open craters like broken bubbles where the steel

¹ Read before the Enamel Division, Pittsburgh Meeting, Feb., 1923.

appeared almost bare. Fig. 1 illustrates one type in which the spots were arranged in streaks which evidently would have been straight and parallel to each other had the steel sheet not been distorted to form the



FIG. 2.—Tea-kettle Sample 8, showing extremely defective lower part, with good upper part and spout.

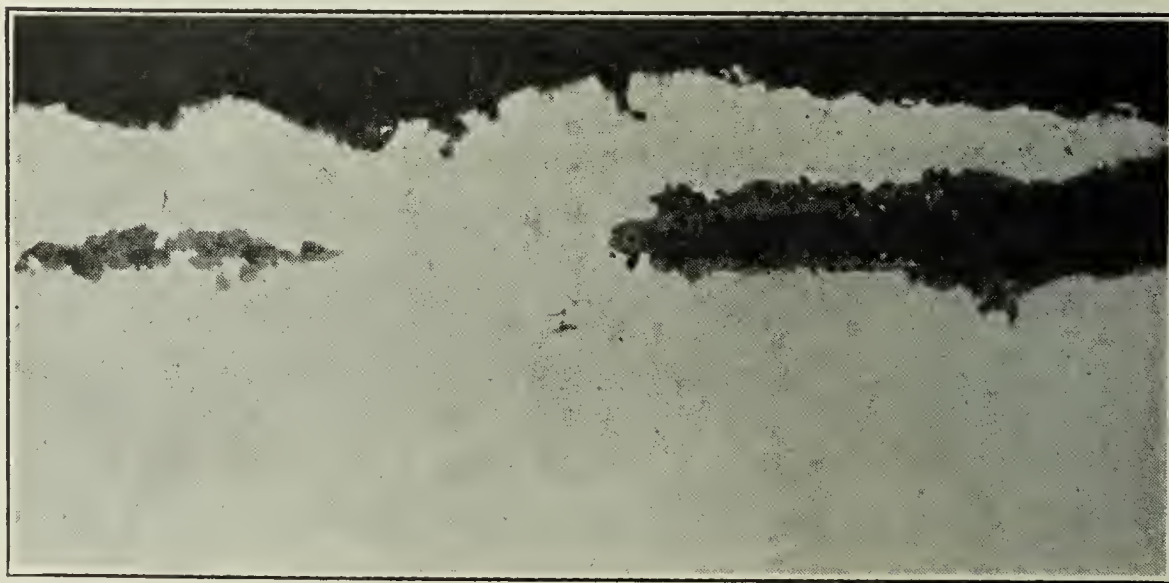


FIG. 3.—Edge of section of the pail, at a defective spot, showing enamel above and steel below, with gray oxide inclusions in the steel at the left. At the right the enamel has penetrated into a larger oxide inclusion.

curved surfaces of the ware. Fig. 2 illustrates the other type in which the spots were irregularly scattered more or less evenly all over the surface.

FIG. 3.—Unetched sections, magnified 200 diameters, of samples showing defective spots arranged in streaks.

Fig. 2 is a tea-kettle, composed of an upper part welded onto a lower part made from a different sheet. This, it is believed, proves that the cause



FIG. 4.—Another view of same specimen as FIG. 6, showing a spot where the enamel has penetrated through a thin layer of steel into a long thin oxide inclusion near the surface of the steel.

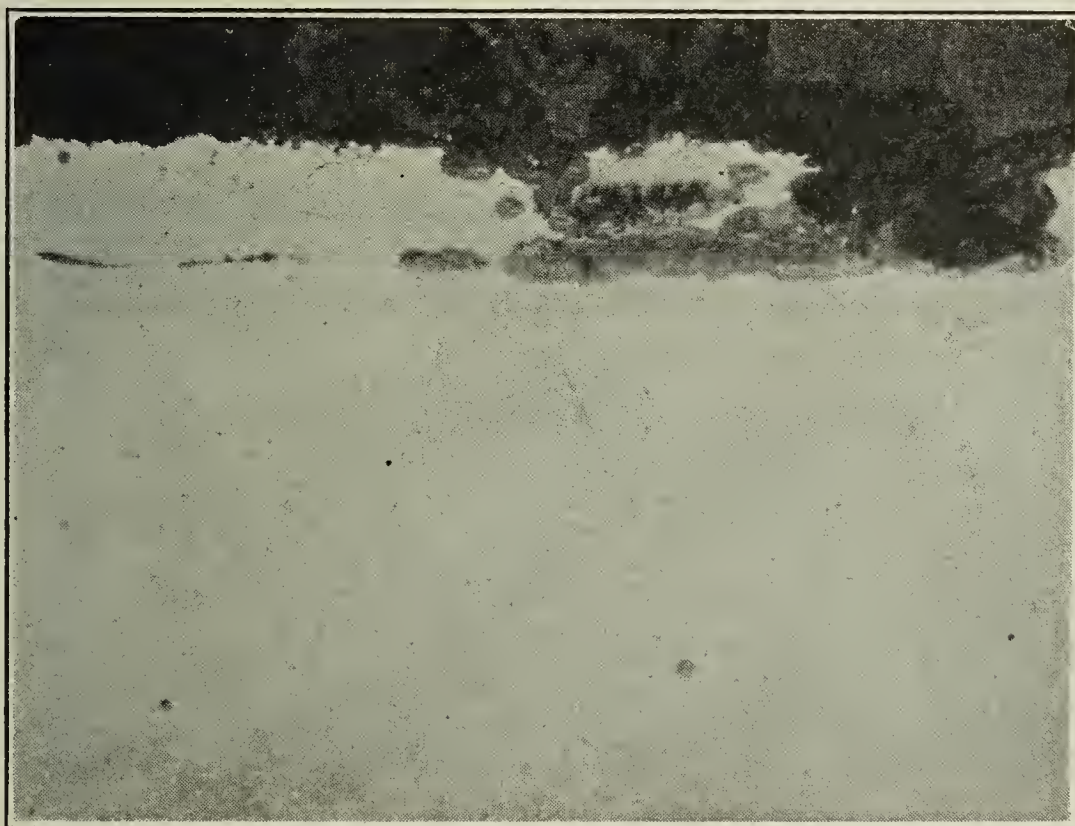


FIG. 5.—Edge of section through upper part of tea-kettle Sample 6, at one of the streaks of defects. The dark gray enamel is shown at the top, and extending down into an oxide layer in the steel. Note the thin slag inclusions at the left of the light-gray oxide.

of the defect did not lie in the temperature of firing the enamel but in the sheet steel.

FIGS. 4, 5.—Unetched sections, magnified 200 diameters, of samples showing defective spots arranged in streaks.

For the metallographic study, numerous sections were cut through the samples at both good and defective locations, and were packed in bundles of four, with red-fiber between them, for polishing. The four sections of enameled ware, with red-fiber between, and brass ends, formed approximately a rough cube, one face of which was polished. In this way per-

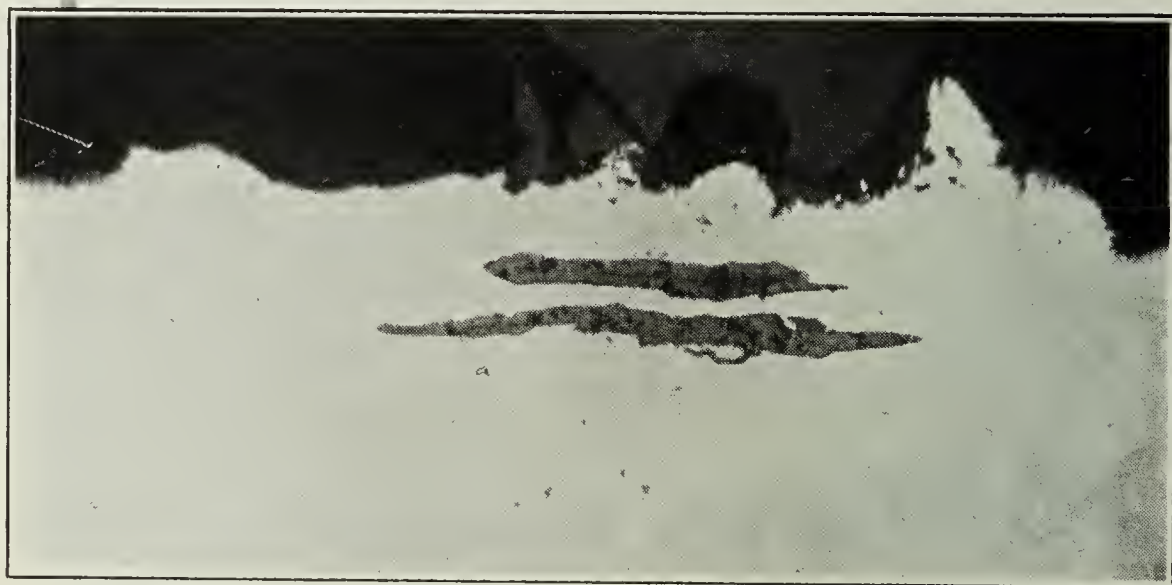


FIG. 6.—Edge of section of small kettle, at a defective spot, showing enamel above and steel below, and two thin oxide inclusions in the steel just below the surface.

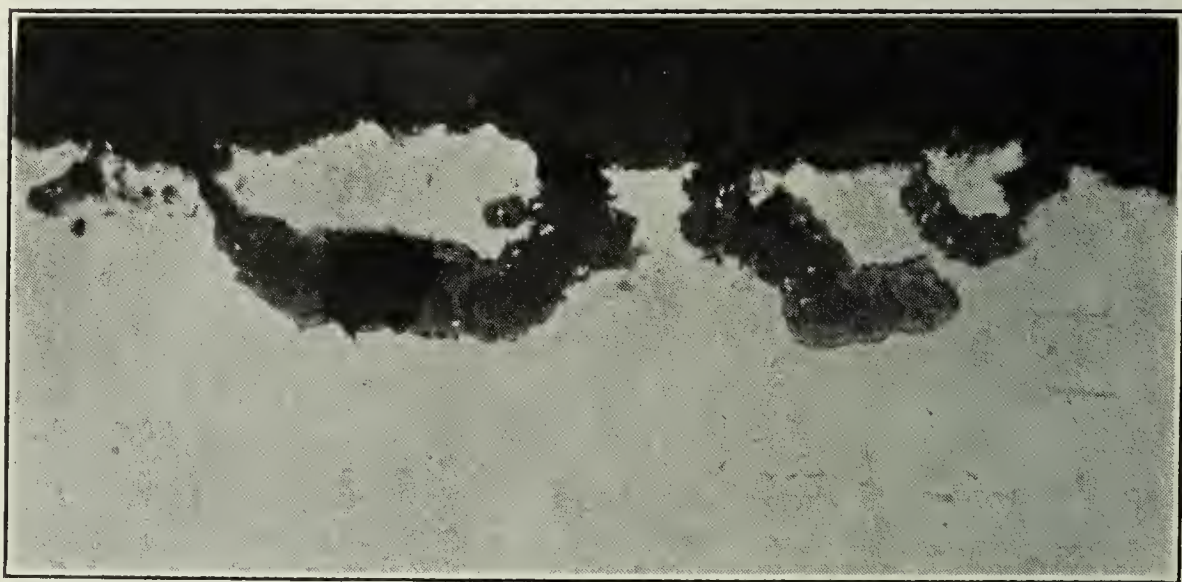


FIG. 7.—Another view of same specimen as FIG. 6, showing penetration of the enamel into the steel with hardly any indication of pre-existing oxide inclusions. Note fine crack or oxide streak near lower right-hand corner.

fectly flat sections of the thin samples could be made smooth enough for examination. The enamel however caused considerable trouble, for it could not be entirely cracked off the steel, and neither could it be retained entirely in the polished sections during the preliminary grinding because

FIGS. 6, 7.—Unetched sections, magnified 200 diameters, of samples showing defective spots irregularly scattered.

its brittleness caused fragments of it to break away continually below the surface of the metal. Thus the steel strips in the polished surface were not uniformly supported along their edges, but depressions existed where pieces of enamel had broken away, and it was impossible to prevent the soft steel from flowing into these depressions to a certain extent during the grinding and polishing. The edges of the steel sections, when examined in the microscope after polishing, appeared for this reason somewhat more rough and irregular than they should be.

All the samples in which the defects occurred in streaks showed the same peculiarities on examination of the polished sections before etching. At places that were not defective the steel appeared normal and fairly clean, but the sections cut through the defective streaks showed slag and oxide



FIG. 8.—Section of defective lower part of tea-kettle Sample 7, showing some of the thin erratic oxide streaks extending down into the center of the sheet.

inclusions in the steel a short distance below the surface of the sheet. The smaller slag inclusions did not seem to have affected the enamel, but the large oxide masses had been in many cases entered by the enamel and these undoubtedly were the cause of the defective spots noted on the surface of the ware. These oxide masses were very similar to inclusions that have been found to have caused blisters in tin-plate and galvanized sheets, and they are believed to be due to scale rolled into cracks in the ingot during manufacture of the steel sheet. In forming the ware from the

FIG. 8.—Unetched sections, magnified 200 diameters, of samples showing defective spots irregularly scattered.

sheet of steel, the oxide mass was evidently shattered, and in many cases the thin layer of metal above the oxide inclusion was probably ruptured. This permitted access of the pickling acid to the included oxide, and later when the enamel was applied and burned on, it also ran down into the oxide and reacted with it, evolving the gases that produced the bubbles or black specks in the white enamel.

Several photomicrographs show the peculiarities of the samples having this type of defect. The enamel is shown very dark in comparison with the steel because in the microscope the illumination is purely vertical, and under this condition the polished metal reflects light much more efficiently than the partially transparent enamel. Iron oxide when polished is intermediate in reflecting power and hence appears light gray in the



FIG. 9.—Section of defective lower part of tea-kettle Sample 8, showing one of the spots where excessive penetration of the enamel occurred, with oxide streaks also down in the center of the sheet.

photomicrographs, but silicate or slag inclusions in steel appear dark like the enamel.

The irregularly scattered defects were studied in the same way. At some of these defects oxide inclusions were found a short distance below the surface of the steel, but they were not nearly as large as those found in connection with defects of the other type. There were many places where the enamel seemed to have penetrated into the steel without any evidence of oxide inclusions having occurred there beforehand, but in most

FIG. 9.—Unetched sections, magnified 200 diameters, of samples showing defective spots irregularly scattered.

instances of enamel penetration there was considerable formation of oxide around the included masses of enamel. In one of the tea-kettle samples this enamel penetration was particularly severe, extending down to the

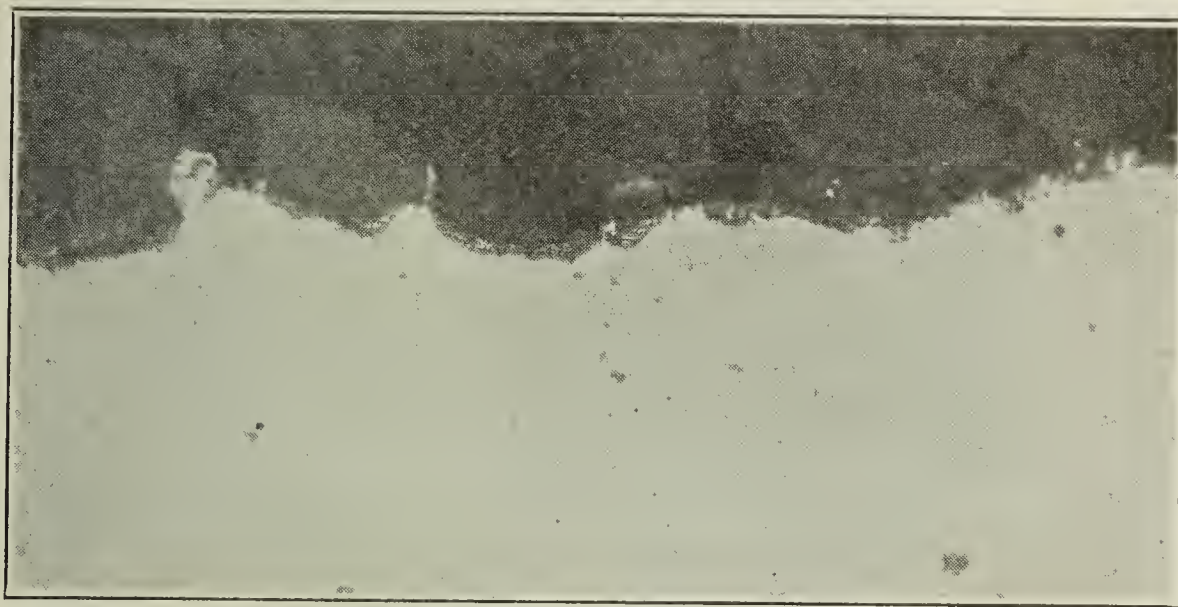


FIG. 10.—Edge of section of oval foot-tub where no defects occurred, showing fairly clean steel and fragments of cracked enamel above it.

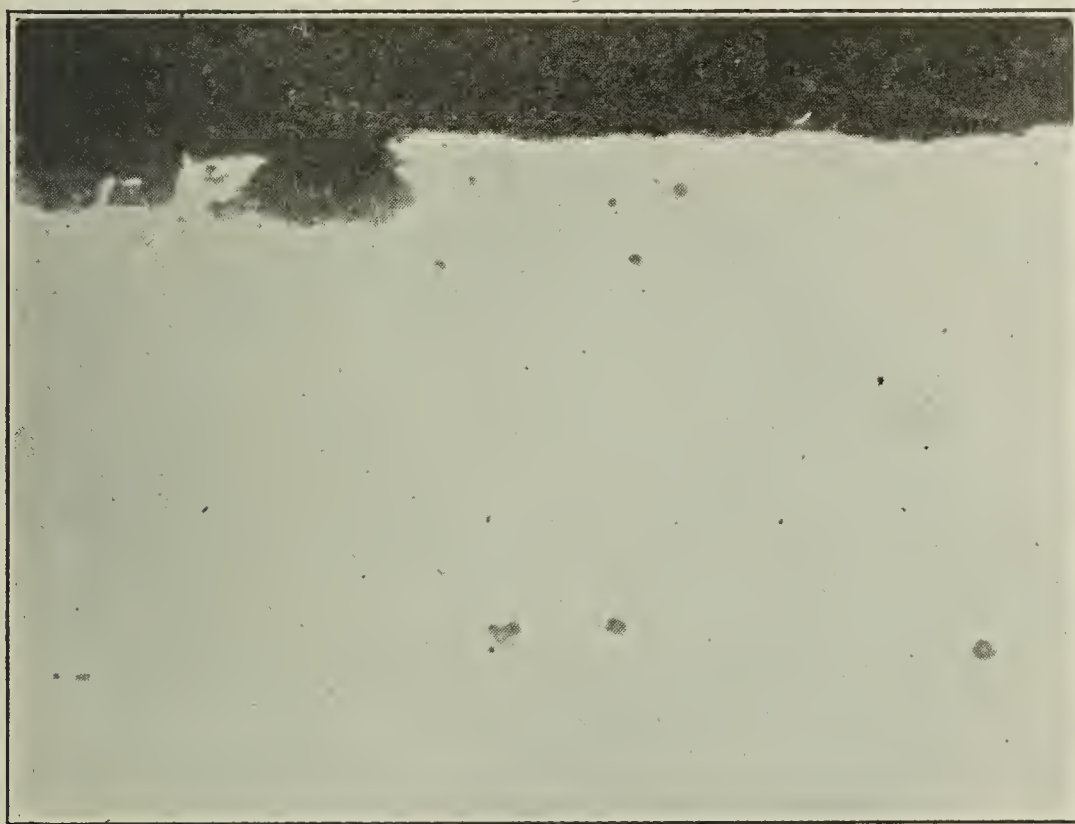


FIG. 11.—Section of good upper part of tea-kettle Sample 8, showing very slight enamel penetration at the edge, and a few small slag and alumina inclusions in the steel.

center of the sheet in many places. In another, iron oxide occurred in thin irregular and erratic streaks extending sometimes to the center of the section. These thin streaks resembled the intergranular cracks that

FIGS. 10, 11.—Unetched sections, magnified 200 diameters, at good parts of the samples, where the enamel showed no defects.

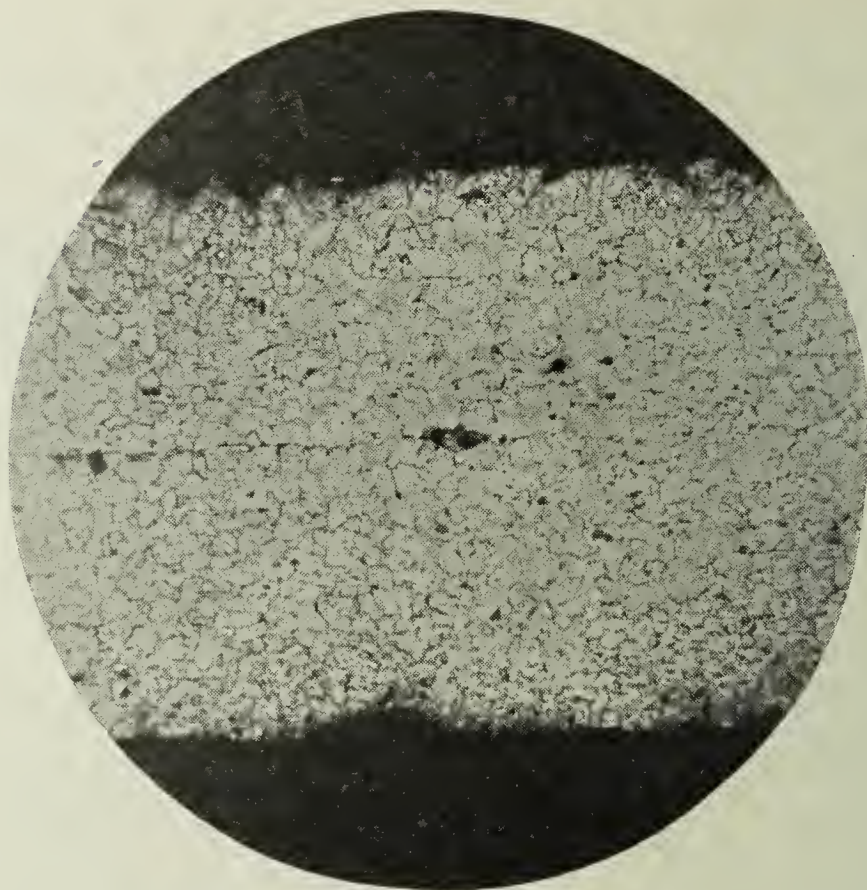


FIG. 12.—Fine and even structure of steel in oval foot-tub, but showing traces of slag along center line of the sheet.

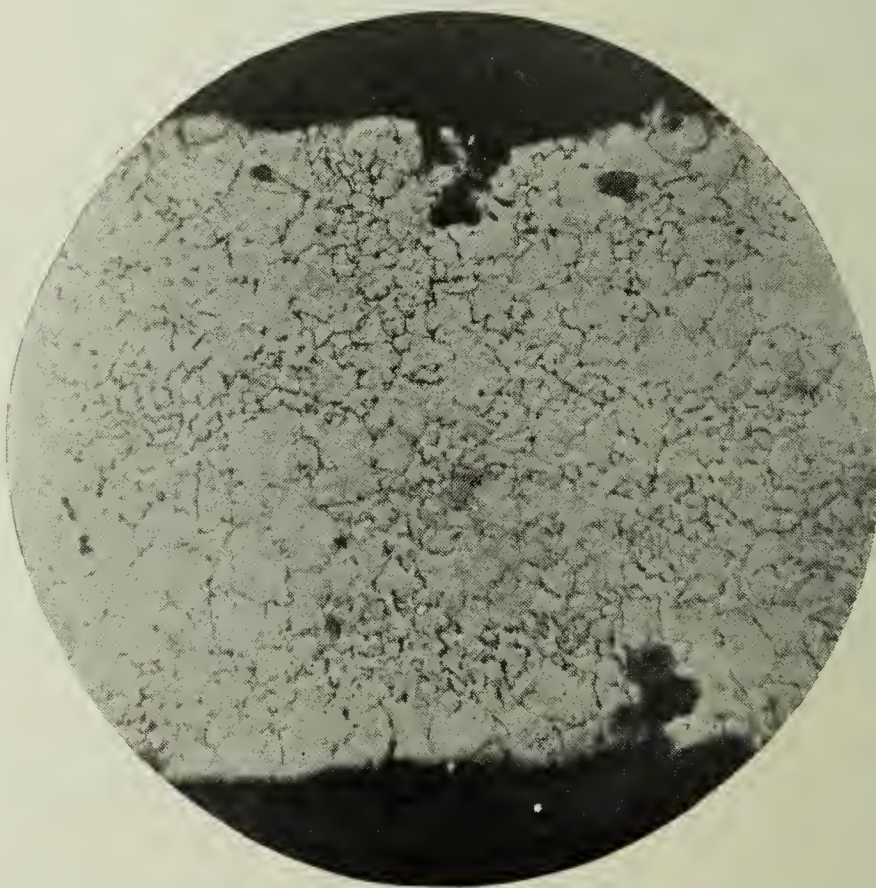


FIG. 13.—Coarse, uneven structure of steel in small kettle, with penetration of enamel at edges of the sheet.

FIGS. 12, 13.—Sections etched with nitric acid and magnified 100 diameters. The black strips at top and bottom of each print are space beyond the edges of the sections.

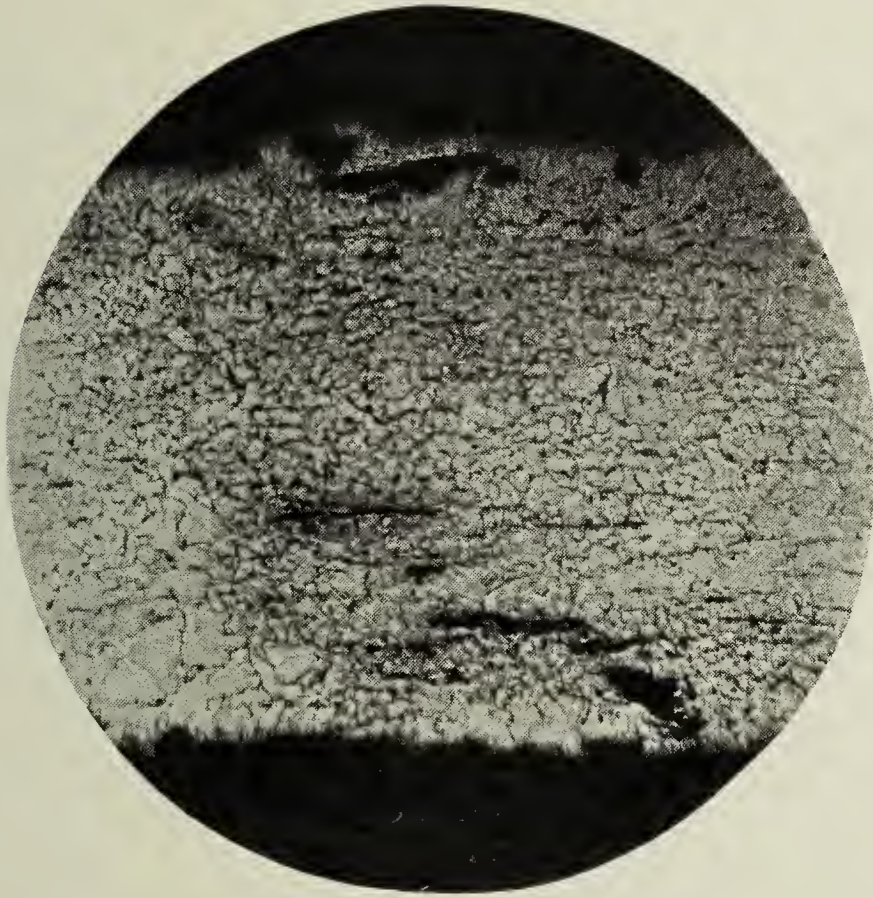


FIG. 14.—Uneven structure, with some coarse grains, in the basin showing elongated dark streaks, apparently cracks, in some of which near the edge the enamel has penetrated.

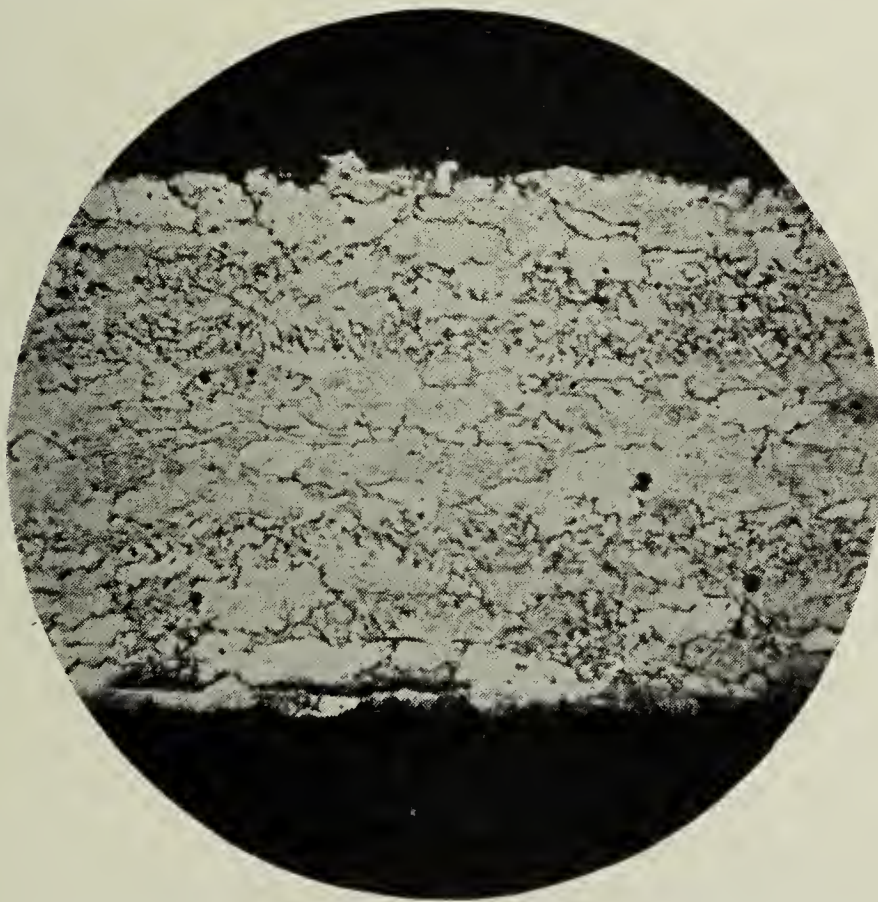


FIG. 15.—Coarse elongated structure of defective upper part of tea-kettle Sample 6, showing fine sorbite particles unevenly distributed, the center of the sheet being almost without sorbite.

FIGS. 14, 15.—Sections etched with nitric acid and magnified 100 diameters. The black strips at top and bottom of each print are space beyond the edges of the sections.

have been found in brass articles which failed from "season cracking." No defect like this could possibly have originated in the ingot or sheet-bar without being much more elongated in the rolling of the sheet, and it does not seem possible that these streaks could have existed before spinning the ware without failure of the material during that operation.

The parts that were not defective in these samples showed slight enamel penetration with oxide at a few scattered points on the edges of the specimens. The interiors of these good specimens contained scattered angular slag particles, or in some instances alumina, and there was no evidence that such small scattered slag particles in the interior of the sheets had any relation to the defects on the enameled surfaces.

The photomicrographs illustrate the inclusions and enamel penetration in the samples showing the second type of defect, and in a good sample just as the previous photomicrographs illustrated the first type. All the photomicrographs of unetched sections were taken at a magnification of 200 diameters.

The specimens were all etched with nitric acid to reveal their microstructure, which was characterized by ferrite grains differing in size and uniformity, with particles of sorbite scattered more or less evenly within and between them. The carbide was present in the form of sorbite because of the rapid cooling through the critical range when the enamel was baked. Some of the samples with the streaky type of defect had good fine structures, so that although one of them showed a poor, segregated structure, this could not be considered important in connection with the defects. In the same way with the other type of defect, some of the good samples had poorer microstructures than some of the spotted samples and no definite connection was indicated between the structure and the defects. A few photomicrographs are shown to illustrate some of the structures of the etched specimens, magnified 100 diameters. The principal observations made on each sample during the microscopic work are noted briefly in the following table:—

Sample	Defect	Inclusions in metal	Microstructure
Oval foot-tub, 1	Spots in streaks	Oxide and slag near surface	Fine and even
Pail, 2	Spots in streaks	Oxide and slag near surface	Fine and even
Upper part of tea-kettle, 6	Spots in streaks	Oxide and slag near surface	Coarse, uneven, and banded
Small kettle, 3	Scattered spots	Enamel penetration	Uneven, rather coarse
Basin, 5	Scattered spots	Enamel penetration	Uneven (fine cracks?)
Lower part of tea-kettle, 7	Scattered spots	Intergranular oxide streaks and enamel penetration	Fine and even
Lower part of tea-kettle, 8	Scattered spots	Intergranular oxide streaks and enamel penetration	Fine and even

Pitcher, 4	None	Alumina	Rather coarse but even
Lower part of tea-kettle, 6	None	A little slag	Coarse and uneven
Upper part of tea-kettle, 7	None	Clean	Coarse and uneven
Upper part of tea-kettle, 8	None	A little slag and alumina	Coarse, with sorbite all at grain boundaries

As has been noted above, the cause of the spots arranged in parallel streaks on some of the samples may be assigned quite definitely to the presence of scale or oxide rolled into cracks in the steel during manufacture of the bar or sheet. The cause of the defect that took the form of spots scattered irregularly all over the enamel is much more obscure. It is obvious, as has been noted, that it cannot lie in the heating during firing of the enamel, since these samples included two instances of an article being made up of parts of different sheets, one of which showed a large number of defects while the other showed none. The microscope did not reveal any distinctive structure in the metal of the defective samples, but showed marked enamel penetration into the steel, and in the worst cases some apparently intergranular streaks of oxide that suggested "season cracks."

In view of all the facts that have been determined in this study, the most plausible explanation of the irregularly scattered defect appears to be that there was excessive corrosion and gas absorption in the defective samples during the pickling process that intervened between the forming and the enameling of the ware. On this assumption the penetration of the enamel and even the intergranular streaks of oxide may be explained, for it is known that under certain conditions of strain in metals, chemical action upon them may take the form of pitting and intergranular attack, leading to separation of the crystals, instead of a uniformly distributed surface action. The fissures produced by such action on the steel during pickling would naturally become oxidized in drying, and when heated in baking the enamel they would become filled with the fused oxide and enamel. Pickling is also known to cause absorption of gas in proportion to its severity, so that the evolution of this gas from over-pickled material by bubbling through the enamel when it is baked on the steel might be expected.

The restriction of the defects in the tea-kettles 7 and 8 to their lower parts is readily explained on the above theory by assuming a different chemical composition of the two pieces of steel used for each kettle. It must be admitted that there is nothing improbable in this assumption. If two pieces of steel of different composition are joined as they were in these tea-kettles and subjected to acid attack, the attack will be largely

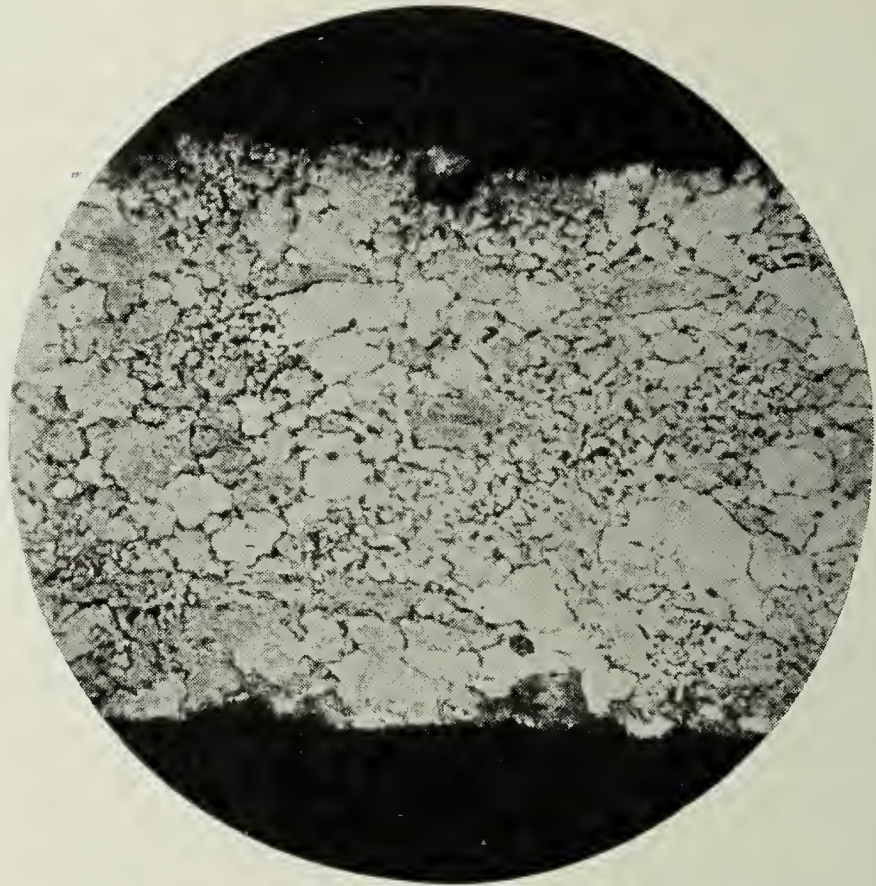


FIG. 16.—Coarse structure, and uneven distribution of sorbite, in the good upper part of tea-kettle Sample 7.



FIG. 17.—Fairly fine and even structure of the defective lower part of tea-kettle Sample 8, showing excessive enamel penetration.

FIGS. 16, 17.—Sections etched with nitric acid and magnified 100 diameters. The black strips at top and bottom of each print are space beyond the edges of the sections.

confined to that piece whose electrolytic potential, as determined by its composition, is the greatest. In these instances the solubility of the lower pieces was evidently considerably greater than that of the upper, so that the pickling required for proper cleaning of the latter was entirely too much for the former.

It was thought that possibly the greater resistance of the upper part of sample 8, for instance, to the pickling as compared with the lower part might be due to the former being copper-bearing steel. Chemical analysis, however, showed 0.10% copper in the lower part and 0.035% copper in the upper part, so that neither steel was commercially copper-bearing. According to the usual experience with copper in steel, the lower part should have been more resistant to acid attack, but other exceptions to the general effect of copper have been found and it does not seem that these copper contents differed sufficiently to contradict the theory outlined above. It has at least been shown that the two sheets used for sample 8 were not of the same chemical composition, and probably differences in some of the elements not determined would account for the different action of the sheets in pickling.

The significant difference may not even lie in the elements usually determined in steel analysis, but may be in the content of some gas, such as oxygen or nitrogen, or some oxide such as MnO. It was shown by G. A. White in "A Metallurgical Study of the Steel Base as Related to Galvanizing" that absorption of hydrogen in pickling became excessive and gave trouble in galvanizing when a certain form of manganese oxide was present in the steel, and that aluminum oxide caused the same trouble. Titanium-treated steel, however, which was "free from dissolved gases and oxides," gave good results in galvanizing. It is very probable that the results in enameling are governed by the same factors, and would be similarly improved by the use of a steel base of a more uniformly high quality, which would not suffer excessive pitting and gas absorption during the pickling operation.

TITANIUM ALLOY MFG. COMPANY
NIAGARA FALLS, NEW YORK

SOME INVESTIGATIONS ON KILN BURNING

BY ROBERT M. CAMPBELL

This investigation which I helped to carry out was conducted similarly to those investigations made by R. T. Stull formerly of the U. S. Bureau of Mines, who made some very valuable contributions toward the more efficient burning of the heavier clay wares. The real purpose of our work was to increase the efficiency of the burning in three ways: to reduce the time to burn, to conserve fuel, and to improve the quality of the ware.

The investigation was a comparison of two burnings. The brick burned were the vertically scored buff burning No. 2 fire clay brick which are the standard product of this plant. The first burn was made with no change in construction of the kiln, method of setting, or firing. The kiln was operated as was the practice at the yard. In the second burn no change was made to the kiln but the water-smoking period was cut down while the oxidation and soaking periods were decreased somewhat.

The data to be obtained on the kilns to be investigated was:

- | | |
|--|---|
| (a) Dimension of kilns (including flues, dampers and stacks) | (g) Analysis of flue gas |
| (b) Quantity of ware set, method of setting and dryness of ware when set | (h) Determination and end of oxidation |
| (c) Quantity of fuel used | (i) Frequency of firing and cleaning of fires |
| (d) Sampling and analysis of fuel | (j) Quantity of ash |
| (e) Temperature (top-middle-bottom) | (k) Sampling and analysis of ash |
| (f) Determination and rate of water-smoking | (l) Sampling of clay |
| | (m) Sample of ware |
| | (n) Data for heat balance |

The kiln investigated was a round down draft kiln of 32 feet inside diameter. It had eight stacks built in the wall with openings (9 × 12). There were eight slanting bar furnaces, commonly known as Dutch furnaces. There was a main flue with eight flues, one leading to each stack and the floor had a "pigeon hole" bottom. The kiln was old and in rather poor condition, leaking air. Due to expansion the walls at the bottom were crowded out and probably the stack openings were reduced. The brick set were the standard buff burning brick. They were flat set and were wet, the mechanical moisture being 3.4%. Coal from the company's own mine was used. It was high in sulphur and clinkered badly. Every eight hours the fires were cleaned, that is after the water-smoking period.

Here is given the analysis of both the coal and clay:—

Analysis of coal		Analysis of clay	
Moisture	0.34	Silica	64.84
Volatile Carbon	28.75	Alumina	25.45
Fixed Carbon	60.32	Iron Oxide	2.87
Ash	10.59	Titanium Oxide	1.44
Sulphur	2.36	Calcium Oxide	0.20

B.t.u. (Cal. value) 13,462
Color of ash Purplish Gray

Magnesium Oxide 0.90
Alkalies 3.62
Loss on Ignition 0.72
Fusion Cone 27 3038°F

By the analysis of the flue gas one is enabled to determine the amount of excess air a kiln uses. Should a kiln use too little air the fuel will not burn to complete combustion thus causing a waste of coal. If the per-

centage excess air is too great all that in excess is needlessly heated up and so is responsible for a good bit of the lack of efficiency. A sample of the flue gas was taken each half hour throughout the burn and for twenty-four hours a day. The gas was collected directly from a pipe inserted in the stack. This particular kiln was of the multiple stack type so half the sample was taken at one flue and the remaining half at that flue on the opposite side of the kiln. The gas was collected in a bottle over water and analyzed by the use of an Orsat for the percentage composition of

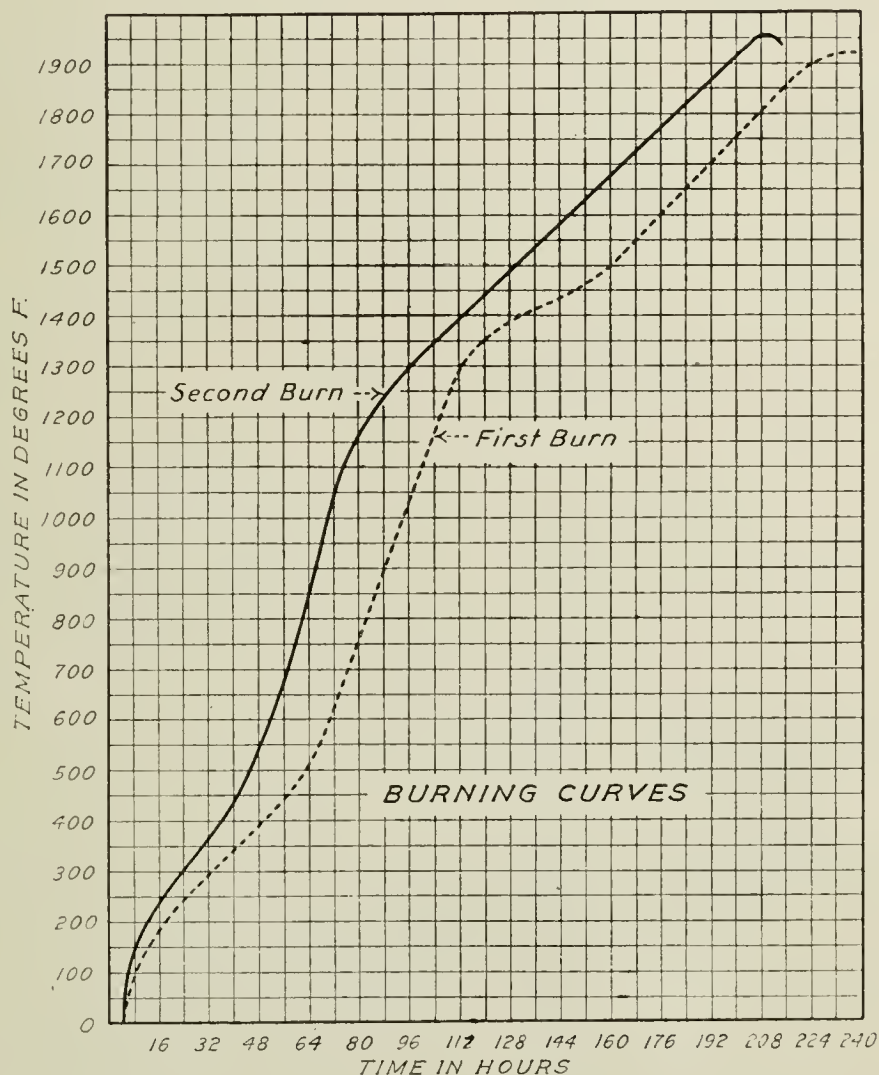


FIG. 1.

the three gases carbon dioxide, oxygen and carbon monoxide. The Orsat is not difficult to operate but in steady use the different solutions which absorb the different gases must be replenished from time to time. Records were kept of the temperature, the presence of moisture in the flues which was determined by inserting in the flue a piece of glass, the condition of the dampers, the amount of coal consumed and any general remarks such as the state of the fires, the presence and color of smoke at the stack, etc. No sample of the gas was taken immediately after firing.

Below are the burning periods as they were taken:

Water-smoking	Up to 650°F
Dehydration	650 to 1100
Oxidation	1100 to 1700
Soaking	1700 to 1950

TABLE I

		FIRST BURN							
		Percentages—Excess air							
		CO ₂	O ₂	CO	(CO ₂ , O ₂ , CO)	N ₂	3.78 × O ₂	Diff.	$\frac{N}{\text{Diff.}}$
Water Smoking	Max.	3.2	18.4	0.5	22.1	77.9	68.6	9.3	837.5
	Min.	1.0	15.8	.0	16.8	83.2	59.7	23.5	354.0
	Av.	1.84	17.5	.18	19.52	80.48	66.2	14.28	564.0
Dehydration	Max.	4.3	18.0	0.5	22.8	77.2	68.0	9.2	839.0
	Min.	1.7	13.1	.0	14.8	85.2	49.5	35.7	239.0
	Av.	3.12	16.3	.13	19.55	80.45	61.5	18.95	424.5
Oxidation	Max.	8.5	18.3	0.3	28.0	72.0	69.2	2.8	2570.0
	Min.	1.5	9.5	.0	10.5	89.5	35.9	53.6	167.0
	Av.	4.03	14.9	.07	19.0	81.0	46.3	34.7	233.5
Soaking	Max.	11.2	15.8	0.7	27.7	72.3	59.7	12.6	573.0
	Min.	4.0	7.0	.0	11.0	89.0	26.5	62.5	142.2
	Av.	7.6	10.2	.13	17.93	82.07	38.6	43.47	189.0

Formula used: $\frac{N}{N-(3.78-O_2)} = R, \frac{R-I}{R} \times 100 = \text{Per cent excess air,}$

TABLE II

		SECOND BURN							
		Percentages—Excess air							
		CO ₂	O ₂	CO	(CO ₂ , O ₂ , CO)	N ₂	3.78 × O ₂	Diff.	$\frac{N}{\text{Diff.}}$
Water Smoking	Max.	4.2	18.7	0.4	23.3	76.7	70.7	6.0	1279.0
	Min.	1.3	14.5	.0	15.8	84.2	55.8	28.4	296.3
	Av.	2.7	16.7	.17	19.57	80.43	63.1	17.33	462.5
Dehydration	Max.	5.0	17.6	0.4	24.0	76.0	66.5	9.5	800.0
	Min.	2.0	13.7	.0	15.7	84.3	51.8	32.5	259.2
	Av.	3.25	16.1	.23	19.58	80.42	60.86	19.56	411.0
Oxidation	Max.	8.6	18.5	0.4	27.5	72.5	69.9	2.6	2790.0
	Min.	1.3	12.1	.0	13.4	86.6	45.7	40.9	212.0
	Av.	3.8	15.6	.12	19.52	80.48	58.97	21.51	374.0
Soaking	Max.	10.1	18.3	0.5	28.9	71.1	69.2	1.9	3740.0
	Min.	1.6	8.4	.0	10.0	90.0	31.8	58.2	154.5
	Av.	5.5	13.7	.14	19.34	80.66	51.79	18.87	428.0

Formula used: $N-(3.78-O_2) = R, \frac{R-I}{I} \times 100 = \text{Per cent excess air.}$

Sheet No. 1.—Method of computing per cent excess air explains the maximum, minimum, average, etc. CO—tells if there is complete combustion or not. 3.78—a ratio of nitrogen to oxygen by vol.).

Sheet No. 2.—Same as No. 1 but calculations for second burn.

Sheet No. 3.—Clearly shows the comparison between the two burnings as to brick set, length of time to burn, coal consumed, per cent excess air, etc.

Sheet No. 4.—These burning curves graphically represent the comparison of the length of time to burn of the two burnings as compared to the temperature in degrees F.

Sheet No. 5.—Heat balance as figured out for the first burn. Efficiency $\frac{\text{Heat out}}{\text{Heat in}}$

TABLE III

RESULTS OF TESTS OF THE TWO BURNINGS ON KILN No. 2

	First burn			Second burn			Difference		Per cent G. Or		
	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Max.	Min.	Av.
No. Brick Set			66,000.00			62,800.00	3,200.00		4.85		
Length of Burn, Hrs.			235.00			212.00	23.00		9.70		
Total Coal, Lbs.			133,253.00			79,960.00	60,293.00		45.17		
Coal per M. Brick, Lbs.			2,019.00			1,161.80	857.20		42.45		
Coal per ton Ware			689.10			396.50	282.60		42.46		
Per cent excess air	Max.	Min.	Av.	Max.	Min.	Av.	Max.	Min.	Max.	Min.	Av.
Watersmoking	837.5	354.0	564.0	1279	296.3	462.5	441.5	57.7	152.6	16.3	18.0
Dehydration	839.0	329.0	424.5	800	259.2	411.0	39.0	20.2	4.6	6.9	3.2
Oxidation	2570.0	167.0	233.5	2790	212.0	374.0	220.0	45.0	8.5	26.9	60.3
Soaking	573.0	142.2	189.0	3740	454.5	428.0	3167.0	12.3	553.0	8.6	126.5
Coal-Watersmoking			27,206.10			19,253.00	7,953.00		29.23		
Coal-Dehydration			9,056.60			11,527.00	2,471.00		27.29		
Coal-Oxidation			61,396.60			25,840.00	35,556.00		59.70		
Coal-Soaking			35,593.30			16,340.00	19,253.00		54.08		
Hours											
Watersmoking			70.0			49.0	21.0		30.0		
Dehydration			25.0			26.0	1.0		4.0		
Oxidation			92.0			84.0	8.0		8.7		
Soaking			48.0			53.0	5.0		10.4		

The heat in is the amount of fuel in lbs. \times calorific val. The heat out is that heat energy which actually goes to heat up the product set in the kiln. It is determined in three steps:

B.t.u. required to bring the ware and water to steam formation

B.t.u. required to change water to steam

B.t.u. required to heat from temperature of steam formation to the maturing temperature.

Conclusion

Records made and kept in this form clearly show the comparison of the burnings and thereby help in the regulating of the kiln to make it more efficient in conserving fuel, and in the length of time to burn.

HEAT BALANCE—KILN No. 2

Started: July 6, 1922, at 6 P. M.

Finished: July 16, 1922, at 12 N.

Set with 66,000 shale -flashed brick

Coal used: 133,253 lbs.—66.63 tons

Calorific value of fuel: 13,462 B.t.u.

Weight of green brick: 5.86 lbs.

Water to evaporate in 1 brick—0.2 lbs.

(1) 5660 (weight of 1000 brick) \times $(212-72)$ 792,400 B.t.u. Required to raise the temperature of 1000 brick to temperature of steam formation.

Average setting temperature—72

$1000 \times 0.2 = 200$ lbs. water in 1000 brick

(2) $200 \times (212-72) = 28,000$ B.t.u. Required to raise the temperature of 200 lbs. of water to temperature of steam.

(3) 200×980 (Latent heat of steam) = 196,000 B.t.u. required to change 200 lbs. of water to steam

(4) $5560 \times (1970-212) = 9,950,280$ B.t.u. required to raise the temperature of 1000 brick from 212 to 1970

792,400 B.t.u. (1)

9,950,280 B.t.u. (4)

(5) 10,742,680 B.t.u.

Specific heat of clay 0.2

(6) $10,742,680 \times 0.2 = 2,148,536$ B.t.u.

28,000 B.t.u.

196,000 B.t.u.

2,148,536 B.t.u.

2,372,536 B.t.u. Total required per 1000 brick.

$133,253 \div 66,000 = 2019$ lbs. coal used for 1000 brick

$2019 \times 13,462 = 27,179,778$ B.t.u.

$$\text{Efficiency} = \frac{\text{Heat out}}{\text{Heat in}} = \frac{2,372,536}{27,179,778} = 8.69\%$$

THE SUITABILITY OF THE TUNNEL KILN FOR BURNING REFRACTORIES¹

BY A. F. GREAVES-WALKER AND S. M. KIER

The final report of the Committee on Fuel Conservation on Tunnel Kilns has been delayed longer than expected due to the desire to gather all data possible, especially from European sources, but principally because it was desired, if possible, to have some practical burning tests made on silica brick. As all efforts in this direction have failed, the Committee has decided to submit the following report of the work accomplished and their conclusions.

Since issuing the preliminary report² the Committee has visited one plant operating a tunnel kiln burning refractories. This kiln is located at the plant of the Ohio Valley Clay Company, Steubenville, Ohio, and is a Dressler.

The kiln is 303 feet 6 inches long and the cross section approximately 4 by 6 feet. It will hold 47 cars each 6 feet long.

Natural gas is used for burning and cone 12 is hooked in center of cars. The entering air has a temperature of 200°F and the exit air 250°F. The maximum charging rate is 2 hours.

The high heat zone is 75 feet long. The lining throughout is Mt. Savage fire brick. Repairs have been very low during the five years of operation, the kiln having been built in 1917-18. The approximate cost was \$120,000 at a period of high costs.

The car repairs have been very low. Refractory car tops last approximately one year.

This kiln is used exclusively for the burning of fire clay shapes, many of which are large and would be classed as difficult. This accounts for the 94-hour burning time. It is practically impossible to figure the capacity of this kiln in 9 inches equivalent or to compare its output with that of the average fire brick plant.

It is safe to say, however, that no more difficult ware is made on any refractories plant in the world and as the losses are practically nil it may be assumed that any type of product made of flint clay—calcine—bond clay mixtures could be handled safely under the same conditions.

Investigation of the European situation reveals the fact that the Germans and French consider the tunnel kiln as perfectly successful for burning fire clay refractories of any type or kind. Installations are numbered by the dozens. This has naturally led to an attempt to develop kilns for burning silica, magnesite and chrome.

¹ Presented at the Tenth Annual Meeting of the Refractories Manufacturers Association, March 23, 1923, New York City.

² See "Preliminary Report of the Committee on Fuel Conservation on the Railroad Tunnel Kiln," *Jour. Amer. Ceram. Soc.*, 5 [9], 602 (1922).

There are, at the present time, two kilns being operated on silica brick entirely and two under construction as a result of the success of the first two.

The operating kilns are at the plant of Dr. Otto and Company at Bendorf Rhein and are known as Otto kilns. Dr. Otto is the well known by-product coke oven builder and operates his own refractories plants.

The first Otto kiln was started in 1913 and was originally 100 meters long. This was found to be too short and it was extended from time to time, principally on the cooling end until in 1919 it had reached a length of 160 meters or 528 feet. A second kiln was built in 1921 of this same length which would indicate that the first was successful.

These kilns are burning silica brick and shapes used almost exclusively in coke oven construction, made from Westerwald quartzite and burned to cone 14. The Westerwald quartzite is a flint or chert and of an entirely different type from those of Pennsylvania and Wisconsin.

An attempt has been made to keep the results obtained from these kilns secret and as a result details are not obtainable. It is known, however, that the product is going into coke ovens and that laboratory tests show the brick to be equal to those burned in down-draft kilns. It is interesting to note that these kilns are operated with producer gas without preheating.

Conclusions

From the investigations made the Committee feels safe in concluding that the tunnel kiln has been developed to a point where it will burn fire clay refractories of any type equally as well as down-draft kilns. These conclusions are based on the results being obtained on the Didier-March, Farber and Ohio Valley kilns and on tests on refractory products in the Champion Porcelain Company's kiln at Detroit, which is operating at cone 18. We have also the results obtained on European operations over a long period of years. It would, of course, be necessary to design a kiln especially for each operation after careful tests of the raw material and mixes and the establishment of a burning curve.

As to the question between the muffle and open type kilns, it is the Committee's conclusion that the open type will burn any fire clay refractories successfully that can be burned in the muffle type and vice versa. First cost would, therefore, naturally govern in the selection.

The question of capacity is an important one. No kiln, as far as the Committee can learn, has been built which produces over 18,000 9-inch equivalent per 24 hours. This is not considered the limit, however, in the present stage of development. From observation of kilns burning other products it is believed that kilns could be built that would successfully burn from 30,000 to 32,000 per 24 hours at cone 12 to 14. It is

very largely a question of total length of kiln, length of high fire zone, fuel used, and method of burning fuel.

In order to produce 32,000 9-inch brick per 24 hours burned at cone 12 the following general specifications would apply.

Length of Kiln—360 feet	Time of burning—72 hours
Car 7' 6" long	$72 \div 48 = 1\frac{1}{2}$ hours charging rate
$\frac{360}{7.5} = 48$ cars in kiln	$24 \div 1.5 = 16$ cars per day
	$2000 \text{ brick to car} \times 16 = 32000 \text{ brick per day}$

This is, of course, entirely theoretical, but several recognized kiln engineers, who have been consulted, agree that the 30,000 capacity kiln is now possible.

As to the feasibility of successfully burning silica refractories in tunnel kilns the Committee thinks that it is possible. It is being done in Europe although at lower temperatures. As was to be expected the problem was one of cooling rather than one of heating up and burning. Cone 18–20 temperatures do, however, present a problem when a large output of product is required. The burning of silica brick is not only a question of bond, but one of inversion which introduces a time factor. It requires exposure to a certain temperature for a certain length of time to produce a commercial silica brick and the only way in which this period can be shortened is to use higher temperatures. For this reason brick now being burned at cone 18 would have to be burned at cone 20 if the burning time was reduced. To produce the necessary volume of heat to burn any considerable number of silica brick would require either a long burning zone or regenerators, which means high construction costs. Furthermore, the inversion points during the cooling period must be taken into consideration in the kiln design.

On account of the size of the average silica brick plant in this country it is not practical to consider a kiln which would produce less than 24,000 9-inch equivalent per day. This is relatively a small unit, but it is questionable whether a tunnel kiln of the standard design could be economically built and operated, which would have larger capacity.

The theoretical specifications for a 24,000 capacity kiln would be as follows:

Length 540 feet	Burning time 6 days = 144 hours
Cross section 5 ft. \times 6 ft. effective	$\frac{144}{72} = 2$ hour charging rate
Car $7\frac{1}{2}$ feet long	$\frac{24}{2} = 12$ cars per day
$\frac{540}{7.5} = 72$ cars	$2000 \text{ brick to car} \times 12 = 24000 \text{ brick per day}$

It is of course, possible that a much larger output could be obtained by building a longer kiln and charging cars at one hour periods, but the car capacity would have to be reduced to 1,500 brick or less.

Such a kiln would theoretically have to be 715 feet long and would produce from 30,000 to 35,000 9-inch per day.

The burning curve on such a kiln would be as follows:

Advance	Drop
40 hours at 20° per hour	7 hours at 20° per hour
19 hours at 65° per hour	13 hours at 123° per hour
18 hours at 20° per hour	15 hours at 40° per hour
—	4 hours at 20° per hour
77 hours	39 hours
Total 116 hours	

A much shorter kiln could be used and the capacity probably increased by making use of the regenerative principle. Designs for such a kiln have been submitted to the Committee and have received very favorable consideration. In this kiln two lines of cars moving in opposite directions are burning at the same time and the use of regenerators makes it possible to build up temperatures in a manner impossible in the standard design. This kiln being designed on entirely new principles, so far as the tunnel kiln is concerned, it is impossible for the Committee to say more than that it is worth the consideration of those interested.

The question of the best fuel to use in connection with a tunnel kiln burning refractories has been given consideration.

In Europe producer gas is used almost exclusively. This is probably due to the possibility of using low grade fuels, such as brown coal, in this manner. Experience in this country also indicates that producer gas is entirely successful.

Producer gas has some disadvantages, however. The deposit of tar and soot in the flue system makes it necessary either to build a double flue system or shut the kiln down and "burn out" periodically. "Burning out" may be necessary every six days or only every thirty days according to the fuel used and the method of operating the producer. The operation requires from 2 to 6 hours depending on the deposit and length of flue system. This is not a serious disadvantage.

A new system recently developed by the Cottrell Company may successfully solve the problem of soot and tar in producer gas. In this system these troublesome ingredients are precipitated electrically and the gas passes through the flue perfectly clean. This would reduce its heating value somewhat unless the precipitated soot and tar could be returned to the producer.

Another disadvantage which may or may not be serious according to the raw material used is that reducing conditions obtain unless special attention is paid to preventing them.

With the application of stokers to tunnel kilns the use of coal has be-

come very efficient and the question of handling it made easy. Methods of using preheated air for secondary combustion have been devised which also adds to the efficiency of coal fuel although this applies equally to producer gas.

It appears that the question of fuels is largely a matter of personal choice. Little need be said about the fuel saving advantages of the tunnel kiln. Other industries have found that they can wipe out their old burning systems and replace them with profit. The report on one tunnel kiln which went under fire six months ago and which cost \$50,000 to build, showed that their saving on fuel alone the first year would amount to \$60,000. As the percentage saving on fuel would be the same in one industry as another, it is logical to presume that the refractories' industry would average a saving of at least 75%.

SILICA CEMENT¹

By E. N. McGEE

ABSTRACT

Composition, requirements and specifications for first quality silica cement are discussed. Adequate control tests for determining its suitability are described, together with such investigations as have been made for the purpose of obtaining a satisfactory cement.

The latter part of the paper deals with the bonding qualities. An investigation showed that the use of molasses greatly improved the bond without affecting the refractoriness.

Introduction

This subject is one which has received little attention, and yet its importance should not be underestimated. The proper selection of a cement or fire clay for laying up brick is just as important as the selection of the brick itself, and should receive as careful and rigid inspection. One of the most important characteristics of silica brick, as has been previously mentioned in several articles, is its ability to resist deformation under load at any temperature below its softening point. It is then obvious that in laying up silica brick, the use of a mortar which may decrease the refractoriness of the brick is injurious, because it affects this characteristic of silica brick, and defeats the purpose for which they are used. Silica brick should, therefore, be laid up with a mortar as nearly like the brick in composition as possible, and still possess suitable working and bonding properties. In a great many instances it would appear that the consumer does not know the character of silica cement nor how to determine its suitability. In fact it seems to be a somewhat general opinion that all silica cements are essentially the same, manufactured in the same manner, and consequently any will answer the purpose satisfactorily.

It is the purpose of this paper briefly to outline the requirements and suitable methods for testing the quality of silica cement, together with such investigations as have been made for the purpose of obtaining a satisfactory cement.

Composition of Silica Cement

Silica cement is usually manufactured of ground silica brick bats with sufficient plastic clay added to give it the proper plasticity and bonding qualities. It is essential that the plastic clay used shall be refractory, of fairly high silica content and that only a sufficient quantity be added to produce the desired results, which is usually about 25%. The proportioning of the clay and bats is usually done mechanically as they go to the mixers, and they are then ground together in the mill to the desired fineness.

¹ Read before the Refractories Division, Pittsburgh Meeting, Feb., 1923.

Some manufacturers substitute raw or unburned ganister rock for part of the silica bats, making the mixture of approximately the following proportions:

50% silica bats
25% ganister rock
25% plastic clay

The fact that the ganister rock expands upon being subjected to heat and will tend to offset the shrinkage of the plastic clay is undoubtedly the chief reason for its use. There is, however, some basis for the claim, as will be shown later, that the addition of the rock also appears to increase the refractoriness of the cement.

There are, then, only two things to be considered in the manufacture of silica cement—*viz.* quality and proportion of plastic clay to be used, and fineness of grind. If ganister rock is used, it is also customary to fix the amount necessary to offset the shrinkage of the plastic clay.

Requirements

Refractoriness is the main requisite of a good silica cement for high temperature requirements, and it should not be impaired even at the expense of the other properties. The cement should not soften at the working temperatures even though it does not flow out of the joints. It should be sufficiently refractory so that it not only meets the requirements of ordinary working conditions, but should also if possible, stand up under any abnormally severe conditions, which may be met. It is absolute folly to build a furnace for high temperature requirements in which the mortar used for laying up the brick is materially inferior to the brick itself. If the mortar fuses or softens and runs out of the joints, it invariably causes a reaction with the brickwork, which is detrimental to its refractoriness. It also leaves open joints, which render the brickwork more readily attacked by flame and more subject to spalling action. For low temperature requirements, if the bonding properties are more important than refractoriness, it may be justifiable to decrease the refractoriness, but even then it is necessary to take into consideration the safety factor, to allow for abnormal conditions. The lower the fusion point of the cement the more detrimental will be the chemical action on the silica brick caused by its fusion.

Next to refractoriness in importance comes plasticity. Silica cement should be sufficiently plastic to possess the necessary working qualities in order that it may spread easily and smoothly with a trowel. It should not settle out or become sandy in the mortar boxes if left standing for several hours. It should possess sufficient bonding qualities to stay in place and hold the brickwork together during the drying and heating up periods. The percentage of plastic clay, which should be used is mainly

dependent upon the character and quality of the plastic clay. This clay should be highly siliceous and refractory, having a fusion point of about Orton cone 28–1635°C.

The working qualities are also in measure dependent upon the fineness of grind. If the cement is rather coarse it will not spread easily and requires a higher percentage of plastic clay to make it stand up in the mortar boxes. It is, therefore, advisable to have the cement ground fine, considerably finer than fire clay because it does not possess the inherent plasticity and the mixing with water cannot break down the grains of silica bats or ganister rock.

The requirements of silica cement are therefore refractoriness, fair plasticity, fair bonding qualities and fineness.

Testing of Silica Cement

On account of the important character of this material, and the great possibility of its varying in quality, it is generally advisable to test each car load of the cement. A representative sample should be taken at the manufacturer's plant before shipment so that the tests will be completed and the quality of the cement determined, if possible, by the time the car has reached its destination. The following tests are those usually employed in determining the suitability of this material.

Refractoriness.—The refractory quality is most readily obtained by determining the fusion point as described in method C 24–20 of the American Society for Testing Materials. This test is accurate, simple in operation and quickly determined. The fusion point of first quality silica cement should not fall below Orton cone 28–1635°C. The softening point of silica brick lies between Orton cones 31 and 32, but the addition of plastic clay decreases this to some extent, depending upon the percentage used and its refractoriness. Obviously the lower the refractoriness of the plastic clay the less that can be used without producing a cement which fluxes at a temperature below that which actual practice has proved satisfactory.

The following data shows the effect of the percentage of plastic clay upon the fusion point of a silica cement.

TABLE I

Per cent ground silica bats	Per cent plastic clay	Fusion point of cement
100	0	Cone 31+
90	10	Cone 31—
80	20	Cone 30
75	25	Cone 29
70	30	Cone 28
65	35	Cone 27–28
60	40	Cone 26–27

Actual fusion point of the plastic clay used in this investigation was cone 27. These mixes were made in the laboratory, and consequently variation in quality of plastic clay or silica bats is entirely eliminated. The results, therefore, should be representative and fairly accurate.

Another investigation carried out on a very large scale at the plant of the United States Refractories Corporation seems to indicate that the substitution of raw ganister rock for the silica bats has a tendency to increase the refractoriness of the cement. In an investigation on such a large scale as this, there may be a small variation in the percentage of clay in the mixers, and there may also be a variation in the quality of the clay itself. The results were, however, very consistent as is shown by the following data. The fusion point determinations were made at the Mellon Institute of Industrial Research.

TABLE II

Per cent plastic clay	Per cent silica bats	Per cent raw ganister rock	Fusion point of cement
25	75	0	Cone 26-27
25	50	25	Cone 28
25	37½	37½	Cone 30
25	0	75	Cone 31½

Fineness.—The fineness of a silica cement may be determined by sifting dry in a sieve-shaking machine of the Ro-tap type for ten minutes. The automatic time stop and mechanical shaking give accurate results if the sample is dry and the sieves are standard and clean. It is important that the cement should be fine in order to provide the proper working qualities, and to allow for the proper laying up of the bricks with thin joints. The Semet-Solvay specifications require that the cement shall be of such fineness that approximately all will pass a 30-mesh screen conforming to the United States Bureau of Standards Specification. Size of opening .0223 inch, diameter of wire .011 inch. We also use the 40-, 60-, 80-, 100- and 200-mesh screen on this test.

The following are actual sifting tests on various silica cements as received from three different manufacturers at the Testing Laboratory of the Semet-Solvay Company.

TABLE III

SILICA CEMENTS

	1	2	3	4	5	6
Through 30-mesh screen	99.4%	99.5%	99.0%	99.7%	99.8%	100%
Through 40-mesh screen	96.8	97.5	93.6	99.5	94.5	99.6
Through 60-mesh screen	75.8	69.9	68.4	90.7	66.1	80.6
Through 80-mesh screen	65.0	59.9	56.5	82.0	54.9	71.6
Through 100-mesh screen	58.7	54.0	49.3	71.3	47.1	62.0
Through 200-mesh screen	44.0	39.8	35.7	48.1	28.7	36.7
Fusion point in cones	28-29	28-29	30	20-26	29	29

Practically 100% of each of these cements pass the 30-mesh screen and consequently they would be acceptable as far as that test is concerned. The fusion point of cement No. 4 is, however, slightly low and would be just cause for its rejection.

3. Analysis.—In a special case like silica cement, a chemical analysis is of considerable value because it not only shows the composition, but also can be used in determining the percentages of plastic clay, which the cement contains, and thus indirectly gives an indication of the plasticity of the cement. The calculation of the percentage of plastic clay is based upon the alumina contents of the silica cement and the plastic clay. If the plastic clay does not vary greatly in quality this method will give fairly accurate results. The following proportion is used to obtain the percentage of clay.

Per cent Al_2O_3 of the clay: ($\%$ Al_2O_3 of the cement—1%) \therefore 100% clay : $x\%$ clay in the cement.

One per cent Al_2O_3 (introduced by the silica bats) is subtracted from the Al_2O_3 of the cement. The remainder is the Al_2O_3 obtained from the clay.

The following chemical analyses of a plastic clay and silica cements, with their actual softening point determinations, illustrate the use made of these tests.

TABLE IV

	Plastic clay	Silica cement—		
		1	2	3
SiO_2	63.96%	84.62%	83.40%	82.00%
Al_2O_3	23.64	7.56	8.90	10.00
Fe_2O_3	2.32	3.12	2.61	2.40
CaO	.24	1.45	1.55	1.35
MgO	.58	.18	.19	.28
Alkalies	3.73	1.33	1.35	1.54
Loss on ignition	5.88	2.02	2.30	2.62
Total	100.35	100.28	100.35	100.00
Fusion point in Cones	20	26	20–26	19
Per cent Plastic Clay by Al_2O_3 calculation		27.7	33.5	38.1
Example—23.64:6.56::100: x				
$23.64\ x = 6.56$				
$x = 27.7\%$ Plastic Clay				

It is interesting to note that the relations between the per cent plastic clay and the fusion points of these silica cements given in Table V (which are samples from car load shipments) are practically identical with the relative values given in Table I, which was a laboratory investigation. The data in Tables IV and V also bear out the statement previously

TABLE V

	Plastic clay	Silica cement		
		1	2	3
SiO ₂	77.48%	90.04%	89.60%	89.02%
Al ₂ O ₃	15.80	4.88	5.66	6.00
Fe ₂ O ₃	.64	1.12	.96	.90
CaO	.26	2.24	1.96	1.85
MgO	.24	.20	.20	.22
Alkalies	.64	.39	.40	.42
Loss on ignition	5.32	1.44	1.60	1.78
Total	100.38	100.31	100.28	100.19
Fusion point in cones	27	29	28	27-28
Per cent Plastic Clay by Al ₂ O ₃ calculation		24.5	29.5	31.6

made that the higher the percentage of plastic clay in a silica cement, the lower will be its refractoriness.

Plasticity.—If the fusion point and fineness tests prove satisfactory it is then only necessary to know whether or not the cement contains a sufficient amount of plastic clay to give it the proper working and bonding qualities. The pail test, which the Semet-Solvay Company uses for this purpose is simple and adequate. The cement is mixed with water to the consistency of dipping mortar and allowed to stand eighteen hours. If after this time it has not settled so as to cake in the bottom of the pail, experience shows that it will spread smoothly, and easily, and not give trouble by settling in the mortar boxes.

Another simple test is also usually made by buttering the cement between the flat surfaces of two 9-inch straight brick, and allowing it to thoroughly air-dry. The cement should then support the lower brick when the upper brick is suspended with the joint in a horizontal plane.

Bonding Qualities of Silica Cement

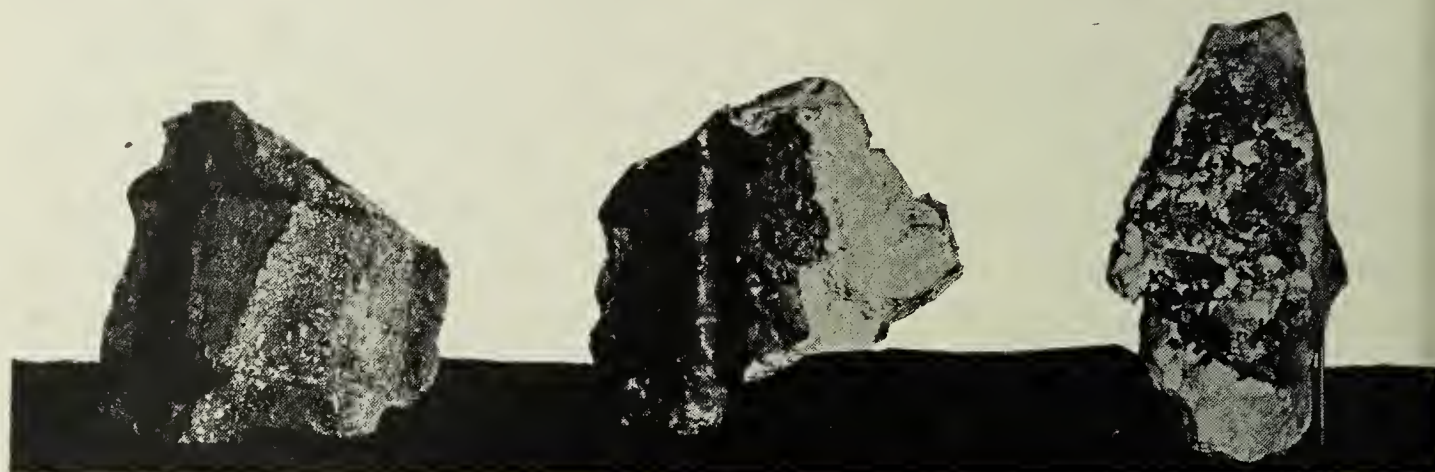
The bonding properties of silica cement with silica brick are very slight even at high temperatures. If the cement is buttered between two silica 9-inch brick and then subjected to a temperature of 1450°C in a test furnace for 72 hours, the bricks will be found to be fairly well bonded together while hot, but when they have been allowed to cool the bond will be very slight. If, however, these bricks are heated under a pressure of fifteen pounds per square inch in the same manner, and then allowed to cool while still under this pressure, it will be found that the bricks are fairly well bonded together. The bonding qualities of silica cement are then very slight unless subjected to considerable pressure or unless the cement is of a sufficiently low refractory quality to cause it to soften or vitrify at the operating temperatures. In the latter case this softening of

the cement causes it to attack the brick and consequently a hard bond is formed, which will not allow the bricks to be separated without breaking them. As has, however been previously stated, the bonding property should not be obtained at the expense of the refractoriness, because it seriously impairs the life of the brickwork. The result of silica cement fusion is shown in Fig. 1 of pieces of bricks taken after actual service in a furnace.

No. 1—Shows the silica cement fused in the joint, but not running out of it.

No. 2—Undoubtedly was subjected to a slightly higher temperature and shows the silica cement fused and run out of the joint, causing a slight attack on the brick.

No. 3—Subjected to a still higher temperature shows the fused mass of brick and cement. This plainly illustrates the result of the attack and impairing of the life of the brick itself.



I

II

III

Effect of Silica Cement Fusion on Silica Brick.

I.—Shows silica cement fused in the joints but not running out.

II.—Shows silica cement fused and run out of the joints.

III.—Shows fused mass of brick and cement.

If it is necessary, however, it has been found that the bonding qualities can be greatly improved, without reducing the refractoriness, merely by the addition of a certain amount of molasses to the water when mixing. Other organic substances might be just as suitable, but molasses is comparatively cheap and gives very satisfactory results. It is not absorbed as readily by the brick as water, and consequently this may cause the cement to fill the pores and then produce a better bond. The burning out of the molasses may also leave carbonaceous matter which tends to bond the cement and brick. Tests have proved that a high refractory cement mixed with part molasses and part water will give a hard bond when heated at 1450°C for 72 hours without being subjected to pressure. In fact the bricks had to be cut apart with a chisel and hammer. They broke

through the cement, leaving part of the cement bonded to each brick. Even at a temperature between 900° and 1000°C a fair bond was produced, which required a considerable pull to break, and as before the break was through the cement. Several tests were made using cements from different manufacturers so that there might be no chance for error, and in each case at temperatures ranging between 1000° and 1450°C the difference in the bond produced with and without the molasses, was unquestionably very marked. Fusion point determinations made on a cement with molasses added showed the same refractoriness as without. It is also a curious fact that silica cement or ground silica bats, if mixed with molasses and applied to a hot silica brick surface, will adhere firmly to the bricks, and consequently it can be used to fill any cracks or crevasses, which may have developed in the brickwork after service.

SEMET-SOLVAY COMPANY
SYRACUSE, NEW YORK

THE DISINTEGRATION OF REFRACTORY BRICK BY CARBON MONOXIDE¹

BY B. M. O'HARRA,² AND W. J. DARBY³

In experimental work carried on at East St. Louis, Ill., in 1916 and 1917, with a furnace of commercial size for the electrothermic dry distillation of zinc ores,⁴ a difficulty that developed was the destruction of the fire-brick lining in certain parts of the large condenser. The condenser was satisfactory in other ways, yielding a large proportion of the zinc as liquid metal, with no blue powder; but in order to obtain a proper length of service from the condenser it became necessary to find and overcome the cause of the disintegration of the lining.

The fire-brick lining of the large retorts in which the charge was distilled showed no disintegration similar to that of the condenser, and in fact required no repairs during the time the plant was in operation, although they were subjected to temperatures of from 1200° to 1300°C, with sudden cooling about once in eight hours when transferred to a new charge. Neither was the condenser lining destroyed in those portions of the condenser which were at comparatively high temperatures, marked disintegration taking place only at temperatures between about 450° and 550°C.

The fire brick used in the condensers were of good grade but showed numerous "iron spots." An examination of the disintegrated brick showed that these iron spots had been filled with fine sooty carbon, and the rupture was due to the increase of volume caused by this deposition of carbon. The carbon results from the reaction $2\text{CO} = \text{CO}_2 + \text{C}$, which takes place actively at temperatures between 450° and 600°C in the presence of catalysts such as metallic iron, which in the present instance would result from the reduction of the particles of iron oxide by carbon monoxide.

This destruction of fire brick by carbon deposition at temperatures

¹ Published by permission of the Director of the U. S. Bureau of Mines.

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⁴ C. H. Fulton, "Electric-resistance Furnace of Large Capacity for Zinc Ore," *Amer. Inst. Min. & Met. Eng., Trans.*, **64**, 188-226 (1920).

⁵ For data on the reaction $2\text{CO} = \text{CO}_2 + \text{C}$, see:

O. Boudouard, "Sur la decomposition de l'oxyde de carbone en presence de l'oxyde de fer," *Compt. rend.*, **128**, 98-101 (1899); "Sur la decomposition de l'oxyde de carbone en presence des oxydes metalliques," *ibid.*, 822-24; "Sur la decomposition de l'acide carbonique en presence du charbon," *ibid.*, 824-25; "Sur la decomposition de l'oxyde de carbone en presence des oxydes metalliques," *ibid.*, 1522-23; "Sur la decomposition de l'acide carbonique en presence du charbon," *ibid.*, 1524-25; "Recherches sur les equilibres chimiques," *Annales de chimie et de physique*, **24**, 5-85 (1901).

R. Schenck and F. Zimmerman, "Über die Spaltung des Kohlenoxyds und das Hochofengleichgewicht," *Ber. Deut. Chem. Gesell.*, **36**, 1231-51 (1903).

R. Schenck and W. Heller, "Über die gegenseitigen Beziehungen der verschiedenen Kohlenstoffmodifikationen," *Ber. Deut. Chem. Gesell.*, **38**, 2139-43 (1905).

T. F. E. Rhead and R. V. Wheeler, "The Effect of Temperature on the Equilibrium

between 450° and 600°C is a well-known, though not common occurrence in iron blast furnaces, and has been discussed by several writers.¹ Firmstone has also described a case in which carbon deposited around angle irons laid in the bed joints of the upper part of a blast furnace lining to such an extent that the lining rings and hoppers were raised as much as nine or ten inches.

Disintegration caused by carbon deposition has also been noted in the lining of producer gas flues, in coke oven refractories, and in the checkerwork of regenerative producer-gas fired furnaces, and is guarded against by the use of fire brick low in iron for these purposes.

Bernhard Osann described some experiments in 1907² in which pieces of refractory material were placed in a porcelain boat in a combustion tube and subjected at a temperature between 450° and 500°C to a current of carbon monoxide passing at the rate of 1.74 liters per minute. In four days the fire brick showed signs of disintegration and in seventeen days fell completely to pieces. Deposition of carbon around particles of iron in the brick was given by Osann as the cause of disintegration.

Carbon deposition around iron spots in the refractory lining of a zinc condenser would naturally be more vigorous than in blast furnaces or in the checkerwork of regenerative furnaces, as the gas in a zinc condenser is, aside from the zinc vapor, nearly pure carbon monoxide, whereas blast furnace gas and producer gas contain much inert nitrogen and considerable carbon dioxide. The small condensers used in the usual retort process of smelting zinc ores are subjected to much rough handling and have an average life of only about ten days, so that if a fairly good quality of fire clay is used in them the effect of carbon deposition is not very noticeable. The large condensers necessary in smelting zinc ores by an electrothermic

$2\text{CO} = \text{CO}_2 + \text{C}$," *Jour. Chem. Soc.*, **97**, 2178-89 (1910); "The Effect of Temperature and Pressure on the Equilibrium $2\text{CO} = \text{CO}_2 + \text{C}$," *ibid.*, **99**, 1140-53 (1911); "The Rate of Reduction of Carbon Dioxide by Carbon," *ibid.*, **101**, 831-45 (1912).

See also G. N. Lewis and Merle Randall, "The Free Energy of Some Carbon Compounds," *Jour. Am. Chem. Soc.*, **37**, 458-70 (1915).

¹ John Pattinson, "On Carbon and Other Deposits from the Gases of Blast Furnaces in Cleveland," *Iron and Steel Inst. Jour.*, **1**, 85 (1876).

Limbor, *Wochenschrift des Ver. deut. Ingen.*, 259 (1878); *Bull. de l'Industrie Minerale*, 2d. ser., tome X, 483 (1881).

F. W. Lurman, *Stahl u. Eisen*, **18**, 168 (1898).

Bernhard Osann, "Einwirkung zerstörender Einflüsse auf feuerfestes Mauerwerk im Hüttenbetriebe," *Stahl u. Eisen*, **23**, 823-29 (1903).

Frank Firmstone, "An Example of the Alteration of Fire-brick by Furnace Gases," *Amer. Inst. Min. Eng. Trans.*, **34**, 427-31 (1904).

Raymond M. Howe, "Blast Furnace Refractories," Appendix, *Amer. Inst. Min. & Met. Eng., Trans.*, **62**, 761-67 (1920).

² Bernhard Osann, "Der experimentelle Nachweis der Schachtzerstörung in Hochöfen durch ausgeschiedenen Kohlenstoff," *Stahl u. Eisen*, **27**, 1626-8 (1907).

process must, however, have a comparatively long life, and it is essential that a refractory material for lining them be found that will withstand the action of carbon monoxide.

From the preceding discussion it will be evident that an iron-free refractory material would probably be suitable. To demonstrate this and to test the effect of carbon monoxide on various refractory materials a series of tests was carried out at the Mississippi Valley Station of the Bureau of Mines, in coöperation with the Missouri School of Mines and Metallurgy. These tests are described in the following pages.

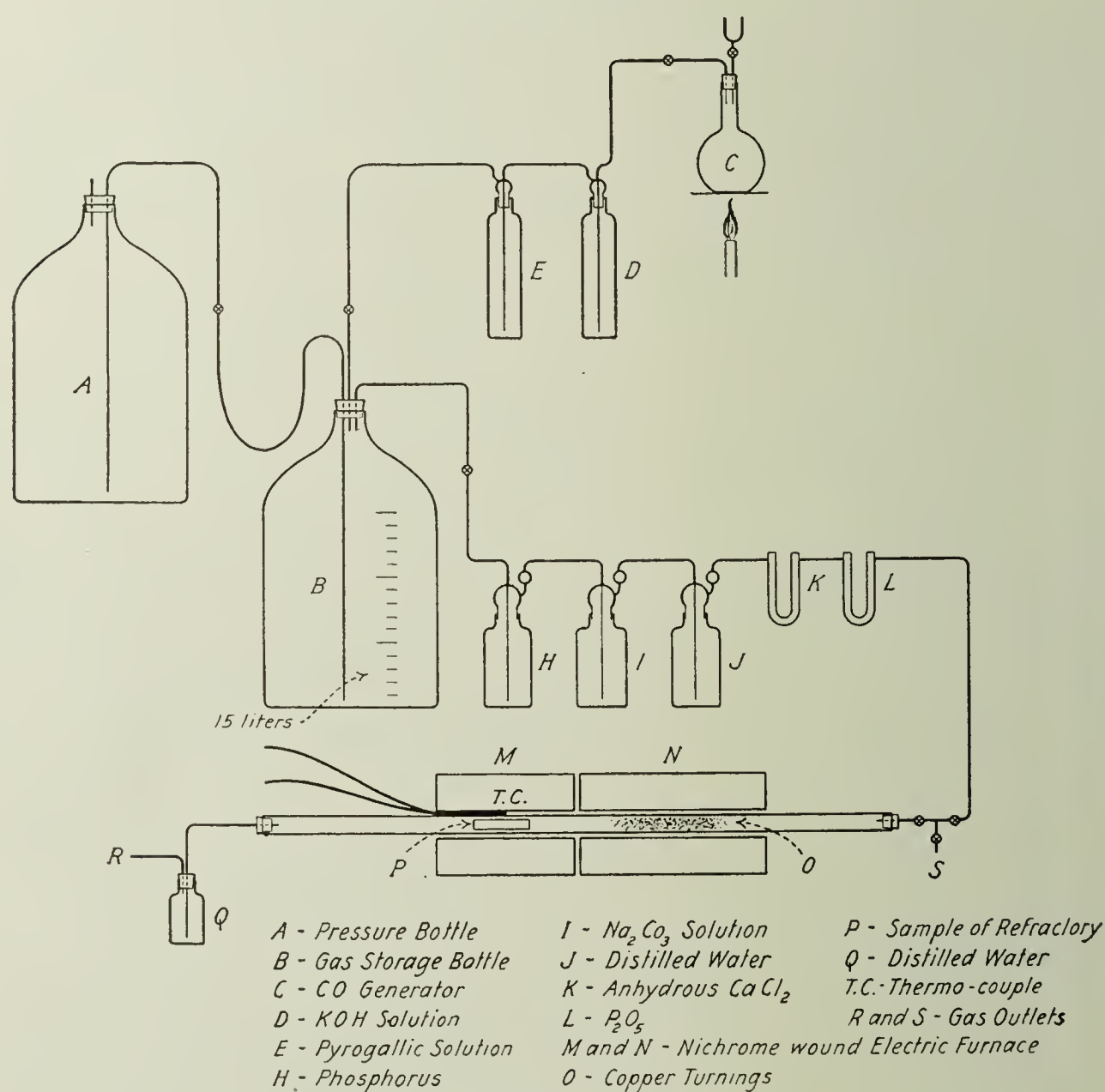


FIG 1.

Apparatus Used

Carbon monoxide for use in the tests was prepared by warming concentrated sulphuric acid with formic acid in a 500 cc. flask, and was freed of carbon dioxide and oxygen by bubbling through concentrated potassium hydroxide solution and potassium pyrogallate solution. The purified carbon monoxide was collected in a large gas storage bottle. The pressure in this storage bottle was regulated by raising or lowering a pressure

bottle of the same size filled with water, which was placed on a small elevator and connected to the storage bottle by means of a flexible siphon. Before the gas was passed over the refractory material it was further purified by being passed over stick phosphorus and through washing bottles containing, respectively, sodium carbonate solution and distilled water, and was then thoroughly dried by passing through U-tubes containing anhydrous calcium chloride and phosphorus pentoxide, respectively. Finally, the last of the oxygen was removed by passing over hot copper turnings and the carbon monoxide was conducted into the combustion tube containing the sample of refractory material, as described below.

The sample of refractory material upon which the effect of the carbon monoxide was to be determined was placed in a pyrex glass combustion tube 20 mm. in diameter, and heated and kept at a constant temperature in a horizontal ni-chrome wound electric resistance furnace. The temperature of the sample was read by means of a thermocouple, the junction of which was placed outside, but touching the wall, of the combustion tube.

A wash bottle containing distilled water was attached to the exit end of the combustion tube to prevent air being drawn back into the apparatus. Samples of gas could be taken at either end of the combustion tube, before or after passing over the sample of refractory.

The rate at which the carbon monoxide was passed through the combustion tube containing the sample varied from 0.1 to 1.0 liter per hour. This was sufficient to keep up a fresh supply of pure carbon monoxide but allowed the carbon dioxide to build up sufficiently so that an analysis of the exit gas would indicate roughly, by the per cent of carbon dioxide found, the rate at which carbon deposition was taking place in the sample.

Tests were made upon four samples of fire-clay brick, one of which was tested at three different temperatures, and upon one sample each of silica brick, magnesite brick, carborundum brick and chrome brick.

Tests on Fire Brick

The first fire brick tested, Fire Brick A, was one which was selected because it contained many large and very noticeable spots, or splotches, of iron oxide. An analysis gave:

Fe_2O_3	3.72%
SiO_2	57.12%
Al_2O_3	41.63%
CaO	0.77%

Figure 2 is a photograph of one end of this brick and shows the iron spots plainly.

Tests were run on Fire Brick A at 550°, 650° and 750°C.

Test No. 1.—In test No. 1, a piece of the brick was subjected to the action of a current of carbon monoxide for 29 hours at a temperature of

550°C. The carbon monoxide gas was passed at an average rate of about 1 liter per hour. Samples of the gas entering the combustion tube contained no carbon dioxide, while four samples taken at different times of the gas after passing over the sample of fire brick contained, respectively

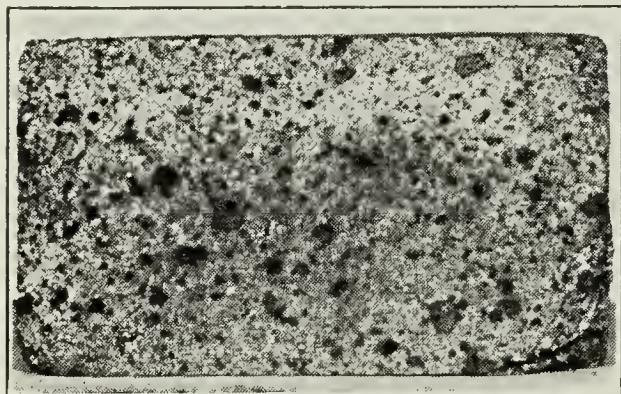


FIG. 2.—Photograph of one end of Fire Brick *A*, showing splotches of iron oxide.

4.4, 3.4, 3.4, and 1.4% carbon dioxide. At the end of 29 hours deposits of sooty carbon were found to have formed at the iron spots in the test piece, and near the larger spots the brick had swelled out and large cracks radiated from the deposits of carbon. *A* and *C*, Fig. 3, are two views of the test piece showing plainly the swelling and cracking caused by the deposition of carbon. *B* is a piece of the original brick, before being exposed to the carbon monoxide.

During the test the brick was subjected to no sudden changes of temperature, nor to any other disintegrating influences other than the carbon monoxide. This fact, together with the fact that the cracks radiated

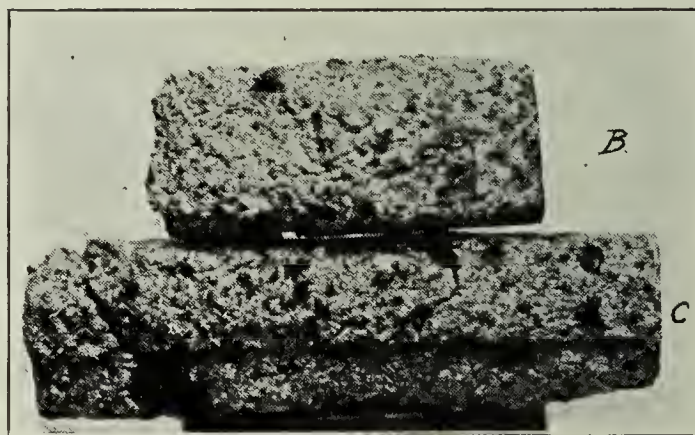
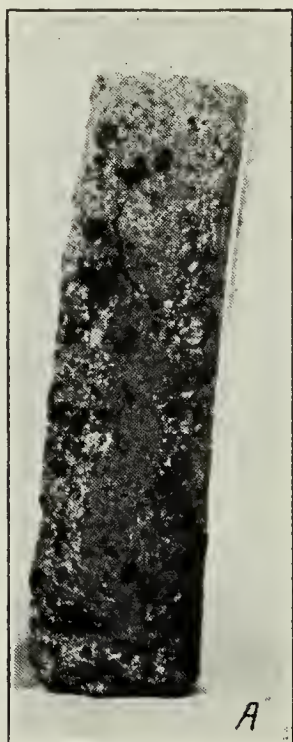


FIG. 3.—*A* and *C*: Two views of a test piece of Fire Brick *A*, after exposure for 29 hours to carbon monoxide at a temperature of 550°C, showing cracks radiating from the larger deposits of carbon. *B*: piece of brick before exposure to carbon monoxide.

from the carbon deposits formed at iron spots in the brick, and that marked swelling took place around these carbon deposits, indicates conclusively that carbon deposited by the reaction $2\text{CO} = \text{CO}_2 + \text{C}$ at iron spots was the cause of the cracking.

Test No. 2.—Test No. 2 was also on a sample of Fire Brick A, and was similar to test No. 1, except that the temperature was held at 650°C. Two samples of gas taken at the exit from the combustion tube contained, respectively, 4.8% and 4.4% carbon dioxide. In this experiment the carbon monoxide was passed at the rate of only 0.2 to 0.3 liter per hour, so the actual amount of CO₂ formed was not as great as in test No. 1. Test No. 2 was continued for 44 hours. At the end of that time the test piece had an appearance similar to that of the one from test No. 1, but the carbon deposit was not so voluminous nor the cracks as large.

Test No. 3.—In test No. 3, also on a sample of Fire Brick A, the temperature was held at 750°C. The velocity of the current of carbon monoxide was about the same as in test No. 2. A sample of the exit gas taken soon after the beginning of the test contained 4.0% carbon dioxide, but samples taken at various later times contained only from 1.2% to 2.0%. The time of this test was 51 hours. Upon examination of the test piece at the end of that time it was found that some carbon had deposited at the iron spots, but the amount was much smaller than in the tests at 550° and 650°C, and no visible cracks or sign of weakening had yet developed.

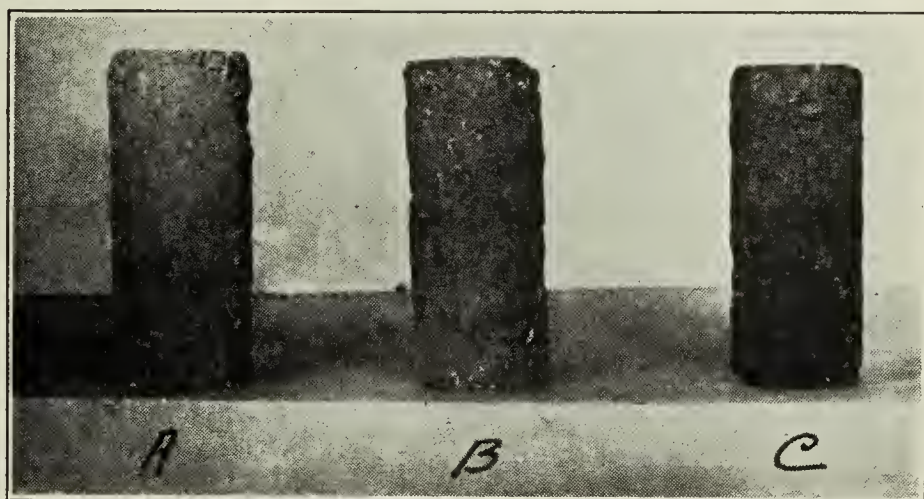


FIG. 4.—Test pieces from Fire Brick B: A, after baking at 650°C; B, after burning at 1300°C; C, after exposure for 113 hours to carbon monoxide at a temperature of 550°C.

Tests Nos. 1, 2, and 3, illustrate the fact that the disintegrating effect of carbon monoxide becomes less as the temperature rises above 550°C.

Test No. 4.—Fire Brick B, used in test No. 4, was a small test brick made up in the laboratory from a mixture of raw fire clay and grog supplied ready for use by a fire brick manufacturing company in response to a request for a fire clay of low iron content that would be resistant to the effect of carbon monoxide. The analysis of the mixture was:

Fe ₂ O ₃	2.47%
SiO ₂	47.04%
Al ₂ O ₃	34.62%
CaO	nil

The test bricks were molded in a small cylindrical briquet mold, dried at 105°C for about 20 hours, baked at 650°C for 20 hours, and finally burned at 1300°C for thirty minutes. None of the brick cracked during

drying or burning. The finished brick contained some specks of iron oxide, but they were of very small size and less numerous than in either Fire Brick A or C.

In this test the temperature was maintained at 550°C. The carbon monoxide was passed through the combustion tube at an average rate of about 0.3 liter per hour. Analyses of the exit gas, after passing over the test piece, showed it to contain from 0.6% to 1.4% carbon dioxide, much less than in any of the preceding tests. This test was continued for 113

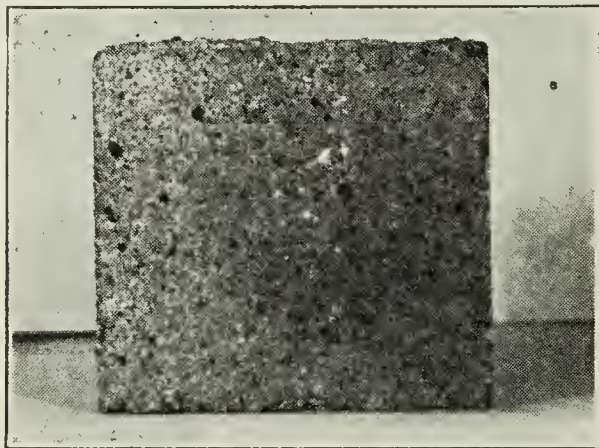


FIG. 5.—Photograph of one end of Fire Brick C.

hours, at the end of which time the brick was darkened by a superficial coating of carbon but contained no marked carbon spots and showed no sign of disintegration. In Fig. 4 are shown three test pieces of Fire Brick B; *A*, after baking at 650°C; *B*, after burning at 1300°C; and *C*, after being subjected to the action of carbon monoxide at 550°C for 113 hours.

Test No. 5.—The brick used for test No. 5, Fire Brick C, was one selected at random from a pile of a standard make of fire brick. The iron spots in it were not as large or noticeable as in Fire Brick A, but were more thickly distributed throughout the brick. Figure 5 is a photograph of an end of this brick. Following is its analysis:

Fe_2O_3	3.72%
SiO_2	64.34%
Al_2O_3	25.83%
CaO	nil

The rate of flow of the carbon monoxide in this test was 0.2 liter per hour, and the temperature 550°C. At the end of 24 hours the test piece had completely fallen to pieces; a large part of it would have passed through a 10-mesh screen. The disintegrated material contained 1.045% carbon. Fig. 6 is a photograph of *A*, a test piece of the brick before exposure to carbon monoxide; and *B*, the disintegrated test piece from test No. 5. No analysis of the exit gas was obtained during this test. A second test at the same temperature on another sample of this same brick was started, and the test piece more closely watched during the first few hours. A sample of the exit gas in this test contained 5.0% carbon dioxide. At the end of the first hour the brick had started to swell and at the end of 12 hours incipient cracking could be seen. The combustion tube cracked, bringing the test to an end, before the brick had completely broken down.

Test No. 6.—Fire Brick D, used in test No. 6, was a small test brick made up in the laboratory, in the same way as Fire Brick B, from a mixture

of equal parts of raw fire clay and grog. These were supplied, like the mixture used for Fire Brick B, in response to a request for a low-iron fire clay to resist the action of carbon monoxide. The analysis of the mixture of clay and grog was:

Fe_2O_3	2.02%
SiO_2	59.48%
Al_2O_3	29.70%
CaO	nil

The temperature of the experiment was 550°C , and the carbon monoxide was passed through the combustion tube at an average rate of 0.23 liter per hour.

Samples of the exit gas taken at various times during the experiment contained, respectively, 1.6, 0.8, 0.7, 1.4, 0.2, and 0.5% carbon dioxide. The test was continued for 120 hours. At the end of that time the test piece was darkened by a superficial coating of carbon but no sign of disintegration could be observed. The appearance of the test piece

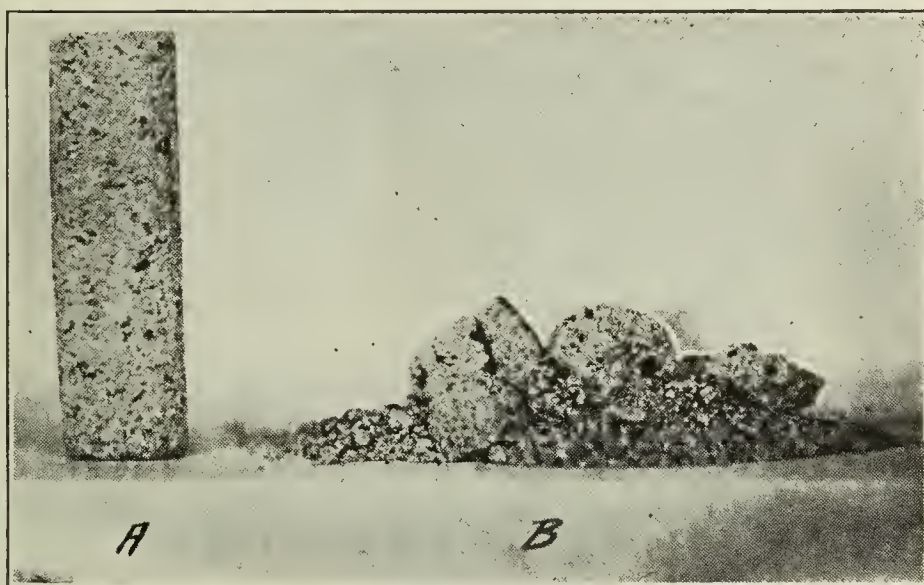


FIG. 6.—A, test piece of Fire Brick C before exposure to carbon monoxide. B, test piece of Fire Brick C after exposure for 24 hours to carbon monoxide at a temperature of 550°C .

before and after being subjected to the action of the carbon monoxide was similar to that of the test piece of Fire Brick B (Fig. 4).

Summary of Results of Tests on Fire Brick.—Tests 1, 2, 3, and 5, show in a conclusive way the manner in which ordinary fire brick containing many particles of iron oxide are broken up by the increase in volume produced by the deposition of carbon at “iron spots,” due to the catalysis by iron of the reaction $2\text{CO} = \text{CO}_2 + \text{C}$. Tests 1, 2, and 3 illustrate the fact that the detrimental action of carbon monoxide is not great at moderately high temperatures, but increases rapidly as the temperature approaches 550°C .

Tests 4 and 6 prove that fire brick of low iron content will withstand the action of carbon dioxide for a much longer time than fire brick of high iron content; in fact the difference in the behavior of Brick A and C, containing 3.72% Fe_2O_3 , and Brick B and D, containing 2.47 and 2.02%, respectively, is surprisingly great. Brick B and D would doubtless in time disintegrate under the influence of carbon monoxide at tem-

peratures favorable for its decomposition into carbon and carbon dioxide, but the tests leave no doubt but that fire brick sufficiently low in iron would withstand its action for a long period of time.

Test on Silica Brick

Test No. 7.—The test piece used for test No. 7 was from a silica brick containing 0.83% Fe_2O_3 and 94.0% SiO_2 .

The temperature was 550°C and the rate of flow of the carbon monoxide was 0.16 liter per hour. A sample of the exit gas from the combustion

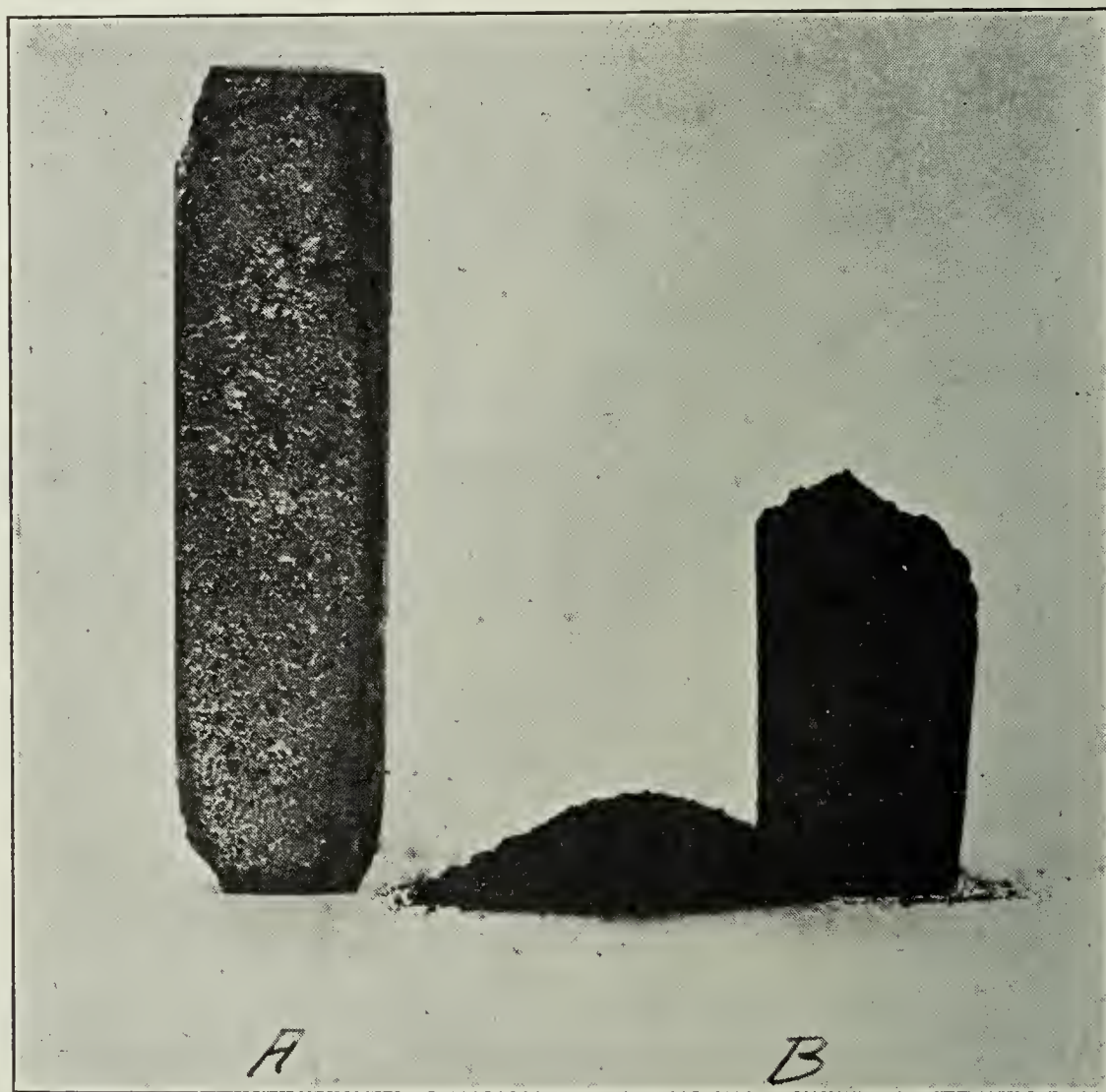


FIG. 7.—*A*, test piece from magnesite brick before exposure to carbon monoxide. *B*, test piece of magnesite brick after exposure for 53 hours to carbon monoxide at a temperature of 550°C .

tube contained 0.6% carbon dioxide. The test was continued for 114 hours. No coating of carbon was formed on the test piece, which was totally unaffected by the treatment.

Test on Magnesite Brick

Test No. 8.—Temperature, 550°C . Rate of flow of the carbon monoxide, 0.15 liter per hour. The sample used for this test was from a magnesite brick having the following analysis:

Fe ₂ O ₃	5.02%
SiO ₂	6.43%
MgO	84.7 %

Two samples of the exit gas contained, respectively, 7.4% and 7.7% of carbon dioxide. After 48 hours the test piece had swelled and cracked and at the end of 53 hours about half of it had fallen completely to a powder. The remainder was friable and could be easily pulverized between the fingers. Both the disintegrated powder and what remained of the original test piece had been changed to a dull black color by the carbon deposited. The disintegrated portion contained 1.056% carbon. Figure 7 is a photograph of *A*, a sample of the original brick, and *B*, the disintegrated test piece.

Test on Carborundum Brick

Test No. 9.—Temperature 550°C. Rate of flow of the carbon monoxide, 0.17 liter per hour. The test piece was a piece of carborundum brick selected at random from a lot which had been purchased for other purposes. It was not analysed.

Two samples of the exit gas during the experiment contained, respectively, 1.0% and 0.4% carbon dioxide. The test was continued for 117 hours. The brick was not affected by the treatment. There may have been a slight coating of carbon which would not have been easily noticeable because of the black color of the original brick, but there was no deposition of carbon of any importance.

Test on Chrome Brick

Test No. 10.—Temperature, 550°C. Rate of flow of the carbon monoxide, 0.28 liter per hour. The test piece was a piece of chrome brick having the following analysis:

FeO	13.9%
SiO ₂	7.9%
Al ₂ O ₃	13.5%
Cr ₂ O ₃	40.0%
MgO	21.1%

Samples of the exit gas contained 1.0% and 1.6% carbon dioxide, respectively. The duration of the test was 121 hours. Sufficient carbon deposited on the brick to color it black, but there was no sign of weakening or disintegration of the brick. This is somewhat surprising, in view of the high iron content. All but a little of this iron is, however, required to form chromite, FeO.Cr₂O₃, with the chromic oxide. There is probably very little iron present in the form of free oxides reducible to Fe at 550°C, and the FeO.Cr₂O₃ evidently does not act as a catalyzer of the reaction $2\text{CO} = \text{CO}_2 + \text{C}$.

Summary and Conclusions

The series of experiments which have been described illustrate forcibly the disintegration of refractories that can be caused by the increase in volume brought about by the deposition of carbon; this deposition of carbon resulting from the decomposition of carbon monoxide according to the reaction $2\text{CO} = \text{CO}_2 + \text{C}$, at temperatures of about 550°C . This reaction does not take place to an appreciable extent in the absence of catalyzers, but metallic iron acts as a catalyzer and in its presence carbon deposits readily. Particles of iron oxide in refractory brick are reduced at low temperatures by carbon monoxide to metallic iron and carbon then deposits around the particles of iron, exerting sufficient expansive force to disrupt the brick. As would be expected the deposition of carbon is less and the disintegrating effect is less as the percentage of iron present as reducible iron oxide decreases. In the absence of iron, or if the iron is present as a compound which is not reduced by carbon monoxide at low temperatures, there is no deposition of carbon and the strength of the refractory is not affected. Carbon deposition and the disintegration caused by it decrease at temperatures above 550°C and are not important above about 750 or 800°C .

Ordinary fire brick and magnesite brick are rapidly disintegrated in an atmosphere of carbon monoxide at temperatures favorable for its decomposition into carbon and carbon dioxide, but iron-free fire brick, silica brick, carborundum brick, or chrome brick (low in free iron oxide) are not affected.

For use as a lining for large zinc condensers, such as are required for the electrothermic distillation of zinc ores, either iron-free fire brick or silica brick would be satisfactory, silica brick being the better of the two. Chrome brick or carborundum brick would also be satisfactory but would be more expensive and would be no better than silica brick.

THE EFFECT OF VARIATION IN FIRING ON THE PHYSICAL PROPERTIES OF VITREOUS CHINA BODIES¹

BY H. H. SORTWELL

ABSTRACT

The porosity, transverse strength, compressive strength and impact strength of ten commercial china bodies were determined on sets of specimens fired in three positions in a kiln in each of ten potteries. The results showed that while there was considerable difference in the maximum strength of the bodies, nearly all of them developed high strength when fired most advantageously. The maximum strength existed over a narrower range in heat treatment than that of complete vitrification. Underfiring and overfiring of this type of body caused serious loss in strength.

Specimens of eleven bodies fired at cones 6, 8, 10, 12 and 14 in a laboratory kiln showed about the same differences in maximum strength as specimens of the same bodies fired in the pottery kilns. In one body only was as high strength developed in the small kiln as in the factory. In most instances the highest strength developed was coincident with complete vitrification and in all the bodies it occurred near or prior to cone 12. There was considerable difference in the range in temperature over which the different bodies were vitrified and were of high strength. While two of the bodies were excellent in this respect, the remainder were vitrified and of high strength through only a narrow temperature range.

Introduction

All manufacturers of ceramic products meet difficulties in maintaining a satisfactory degree of uniformity in their product. Especially is this true in the manufacture of vitreous wares, including hotel china, which should be uniformly vitrified so as not to discolor badly when the body is exposed by the loss of portions of the glazed surface by chipping, but which at the same time should not be fired to the point where the structure becomes glassy enough to be brittle.

Numerous factors cause variations in the ware, including the lack of uniformity in composition and fineness of the raw materials, the details of body preparation, the methods and workmanship employed in forming the ware, and the firing. Without doubt, the firing is the most variable factor in the manufacturing processes. Uniformity of heat treatment throughout commercial kilns is difficult to attain, and the lack of uniformity affects the ware in greater degree than the other causes of variation.

In discussing specifications for hotel china, the question of requirements for uniformity of ware had to be considered. At the meeting of the Research Committee of the United States Potters Association at the Bureau of Standards in April, 1922, this subject was discussed and it was decided that an investigation of the uniformity of the bisque obtained in vitreous china kilns would be of value to the potters and of general interest to the ceramic industry as a whole.

¹ Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

While the volume of work reported on vitreous body compositions is large and does not need reviewing in detail here, only one investigation of commercial bodies of this type has been published. In the Bureau of Standards laboratory Wright and Sewell¹ studied several bodies in use at that time on a laboratory scale, confining their work mainly to the physical properties of the body "clay" and the porosity-temperature relations during firing.

All of the heat treatment measurements in this work were made by pyrometric cones in order to conform to the factory practise in the potteries which coöperated in the work.

Scope of the Investigation

Through C. E. Jackson, chairman of the American Vitrified China Manufacturers Association, it was arranged for a member of the Bureau staff to visit the potteries of the Association for the purpose of making specimens for the determination of porosity, transverse strength, compressive strength and impact strength. It was desired that the pieces from all the potteries be made by the same man to eliminate as far as possible the personal factor in the preparation of the specimens and to insure uniformity in the size of the pieces.

Enough specimens were made so that three sets could be fired in a kiln in what were considered the hottest, average, and coolest parts, one complete set in each position. In most cases the specimens were placed in the first, second and third rings. Each set was put in one sagger with cones and after firing, the specimens, together with the cones, were forwarded to the Bureau laboratory for testing.

In addition to the study of the uniformity obtained in the commercial kilns, an investigation of the variation in the physical properties of the bodies over a much wider range in temperature was made. Each of the potteries interested shipped one hundred pounds of plastic body to the laboratory, where it was made into similar pieces and fired at cones 6, 8, 10, 12 and 14 in a small natural draft gas-fired kiln. The burns were of about thirty hours duration. The heat treatment as shown by cones in the saggars and on the bags varied by less than half a cone in different parts of the kiln in each burn.

Testing Procedure

For the determination of the transverse strength, bars $6 \times 1 \times 1$ inches were pressed from the plastic body in brass molds by the usual method. Twelve bars were made for each position in the kiln and the results represent the average of at least ten. The fired pieces were broken

¹ J. W. Wright and S. I. Sewell, *Jour. Amer. Ceram. Soc.*, 2 [4], 282 (1919).

over a five-inch span in an Olsen transverse testing machine of 1,000 lbs. capacity. The broken specimens were measured for breadth and depth and the moduli of rupture computed.

The broken transverse specimens were used for the absorption, porosity and bulk specific gravity determinations. The dry weighed pieces were saturated with water by boiling under a vacuum for two hours and the calculations made by the usual formulas.

The compression test specimens were made by pressing the plastic body into cylinders two inches long and one inch in diameter in plaster molds. Six cylinders were fired in each set, and after firing were broken in a one hundred thousand pound capacity Riehle testing machine. The results represent the average of at least four specimens in each set.

For the impact tests discs five by one quarter inches were jigged by experienced jiggermen in each pottery. The specimens were broken by striking them in the center with a six ounce hammer suspended on a wire arm making the total length of the suspension two feet. The discs were supported against three steel balls equidistantly spaced in a ring three and one quarter inches in diameter. The first blow was equivalent to 0.025 foot-pounds of energy and each blow was increased by this amount.

Results of Specimens Fired in Potteries

The results show the uniformity of the product in one kiln in each pottery and it is to be expected that unless very bad firing conditions obtained, the specimens in at least one part of each kiln would have approximately the maximum strength possible to be developed in the body by the most advantageous firing treatment.

Table I consists of the numerical results for the specimens fired in the potteries. Fig. 1 shows the apparent porosities in the different parts of each kiln. Bodies 2, 3, 5, 8 and 10 were uniformly vitrified. Body No. 7, which is no longer being used, was uniform in porosity, but in no part of the kiln was it sufficiently vitrified for this type of ware. The kilns containing

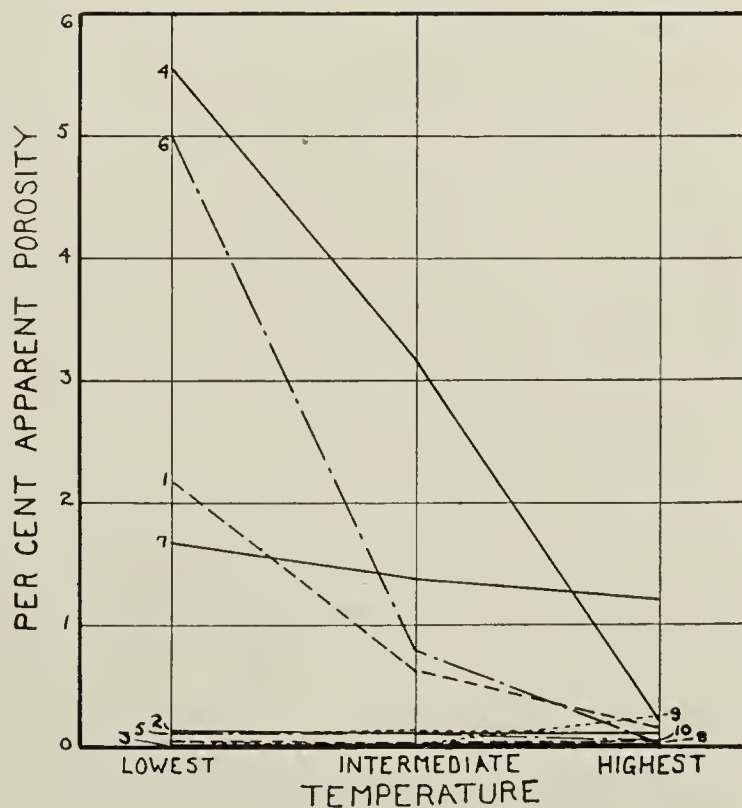


FIG. 1.—Porosity of specimens fired in potteries.

Nos. 1, 4 and 6 were not sufficiently fired to produce uniform ware throughout. While the specimens in the first ring were properly vitri-

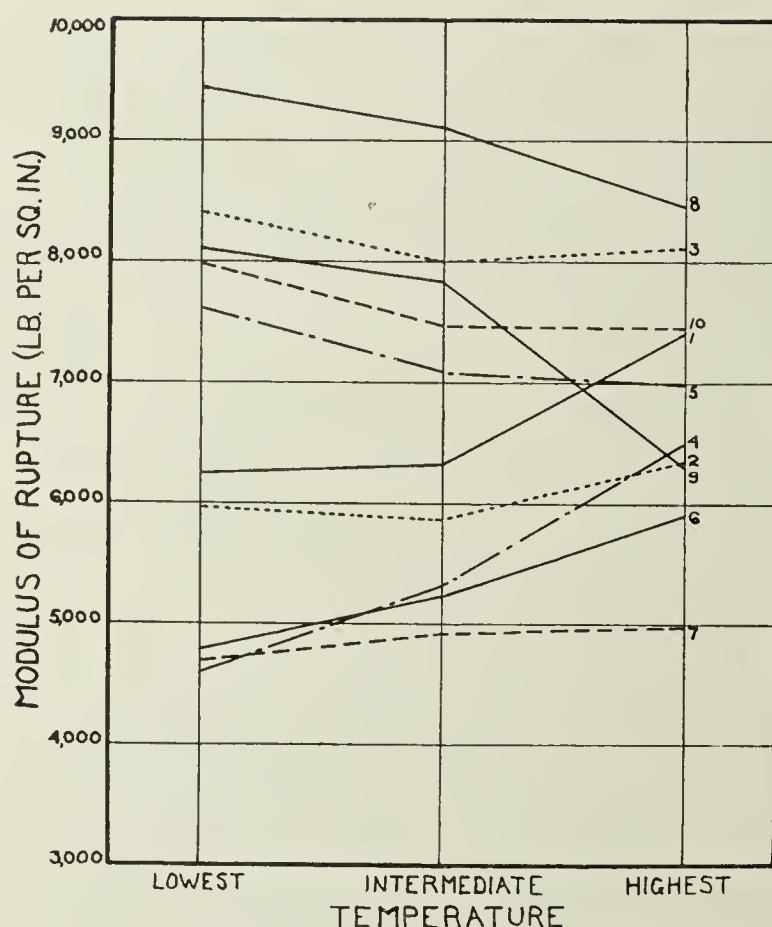


FIG. 2.—Transverse strength of specimens fired in potteries.

when fired under the best conditions obtained in these kilns, six of the bodies showing a maximum modulus of rupture above 7,000 pounds per square inch, and two others between 6,000 and 7,000 pounds. The effect of the underfiring of Nos. 1, 4 and 6 on the transverse strength is clearly shown. The specimens which were not vitrified were considerably lower in strength than those which were properly matured. The average modulus of rupture of the overfired specimens of body No. 9 was almost 2,000 pounds per square inch lower than the maximum strength developed, showing the serious loss of strength which occurs when a commercial kiln of this body is slightly overfired.

Although the results of the compression tests were not as consistent as those for the transverse strength, the average

fired, those in the second and third rings were porous. The kiln containing body No. 9 was overfired. In this case the specimens in the second and third rings were properly vitrified, but in the first ring in which the heat treatment was more severe by one cone, the porosity had risen to 0.24 per cent.

The moduli of rupture are presented graphically in Fig. 2. The maximum transverse strength developed in each body varied from 4975 pounds per square inch for No. 7 to 9444 pounds per square inch for body No. 8. Most of the bodies tested had good strength

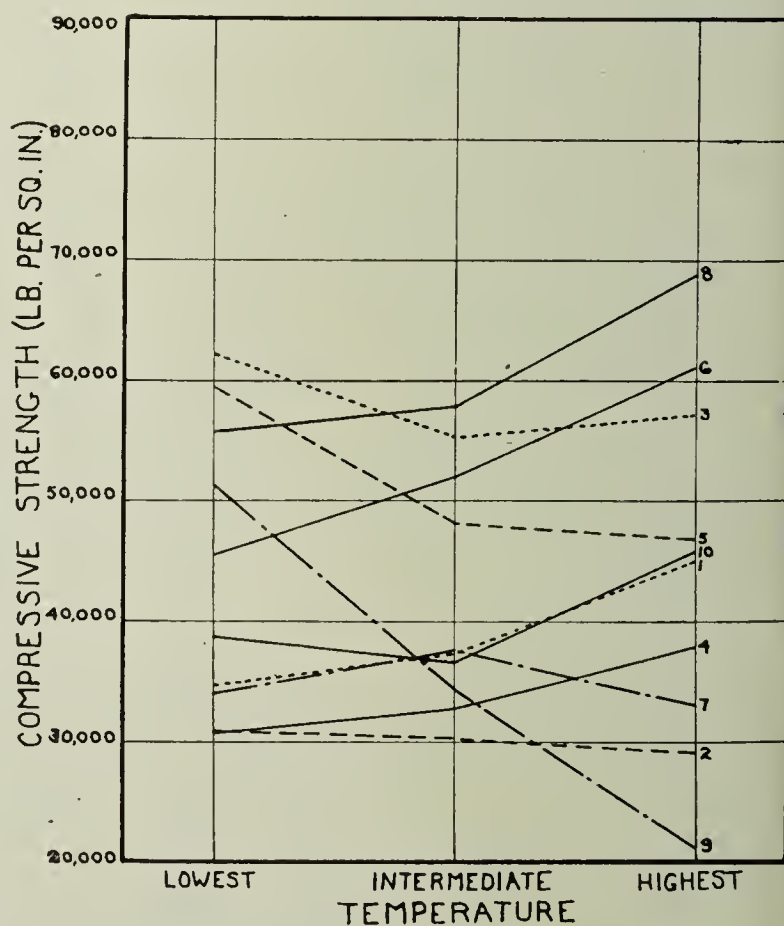


FIG. 3.—Compressive strength of specimens fired in potteries.

results given in Fig. 3 show the same general trend. The underfired specimens of Nos. 1, 4 and 6 were lower in compressive strength than the vitrified pieces, and the overfiring of No. 9 caused a reduction of 50 per cent in the ultimate compressive strength of that body.

The maximum compressive strength developed in these bodies varied from 31,000 pounds to 69,000 pounds per square inch. Body No. 8 which had the highest crossbreaking strength had the highest compression strength also and No. 7 which was not vitrified and had the lowest modulus of rupture failed at the lowest stress in compression. The variation in compressive strength shown by specimens of the same body uniformly vitrified would indicate, after allowing for experimental error, that the temperature range in which the maximum compressive strength is developed is not as wide as the vitrification range.

The results of the impact tests on the discs are shown in Fig. 4. The specimens of body No. 8 withstood much greater blows than those of the other bodies, which was due in part to the fact that the specimens were about 20% thicker than the others. While the impact strength is not a direct function of volume or thickness, differences of that magnitude would affect the results. In general, the impact test results are consistent with the strength of the bodies in the other tests, but the differences in the various parts of each kiln were not great. The higher fired specimens of each body, with the exception of No. 10, were of lower impact strength than those in the lighter fired portions of the kilns.

The higher fired specimens of each body, with the exception of No. 10, were of lower impact strength than those in the lighter fired portions of the kilns.

Figures 5 to 14, inclusive, present graphically the assembled results for the specimens in each of the commercial kilns and show clearly the variations which occurred. Figs. 6, 7, 9, 11, 12 and 14 show bodies 2, 3, 5, 7, 8 and 10 respectively which were fired to uniform porosities throughout the kiln. Bodies 2, 3 and 7 were uniform both in porosity and in strength. While the specimens of No. 5 were equally vitrified, the drop in transverse, compressive and impact strengths shows that the firing of

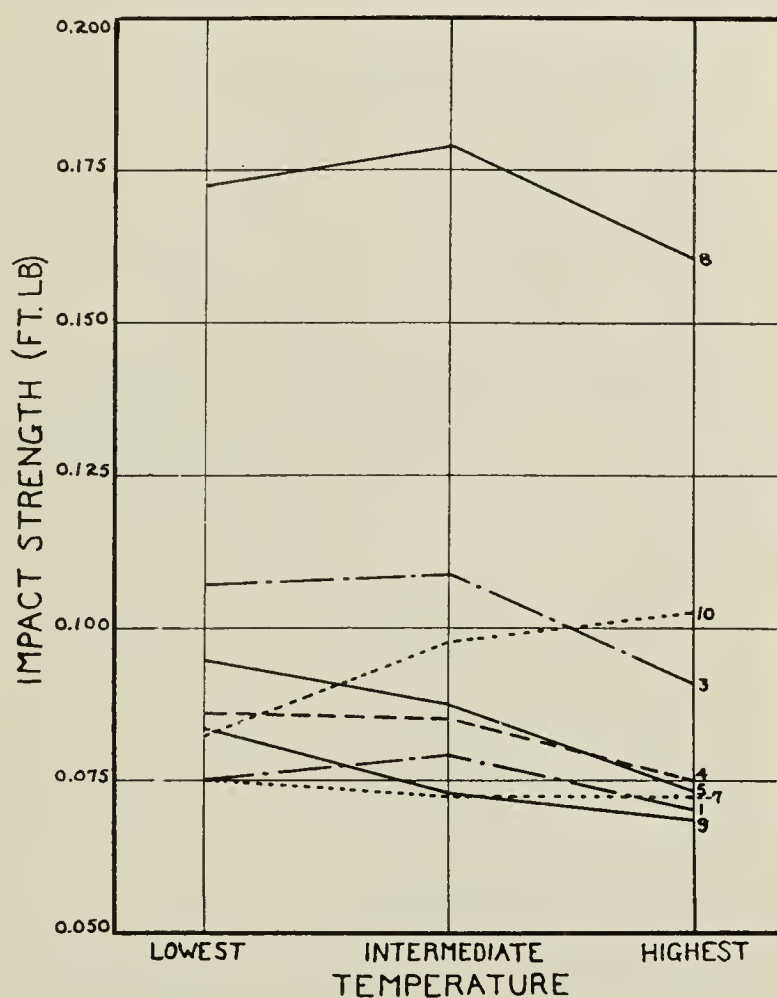


FIG. 4.—Impact strength of specimens fired in potteries.

the kiln was carried slightly past the point where the maximum strength throughout would have been obtained. Bodies 8 and 10, of uniform porosity, were increasing in compressive strength, while the moduli of rupture

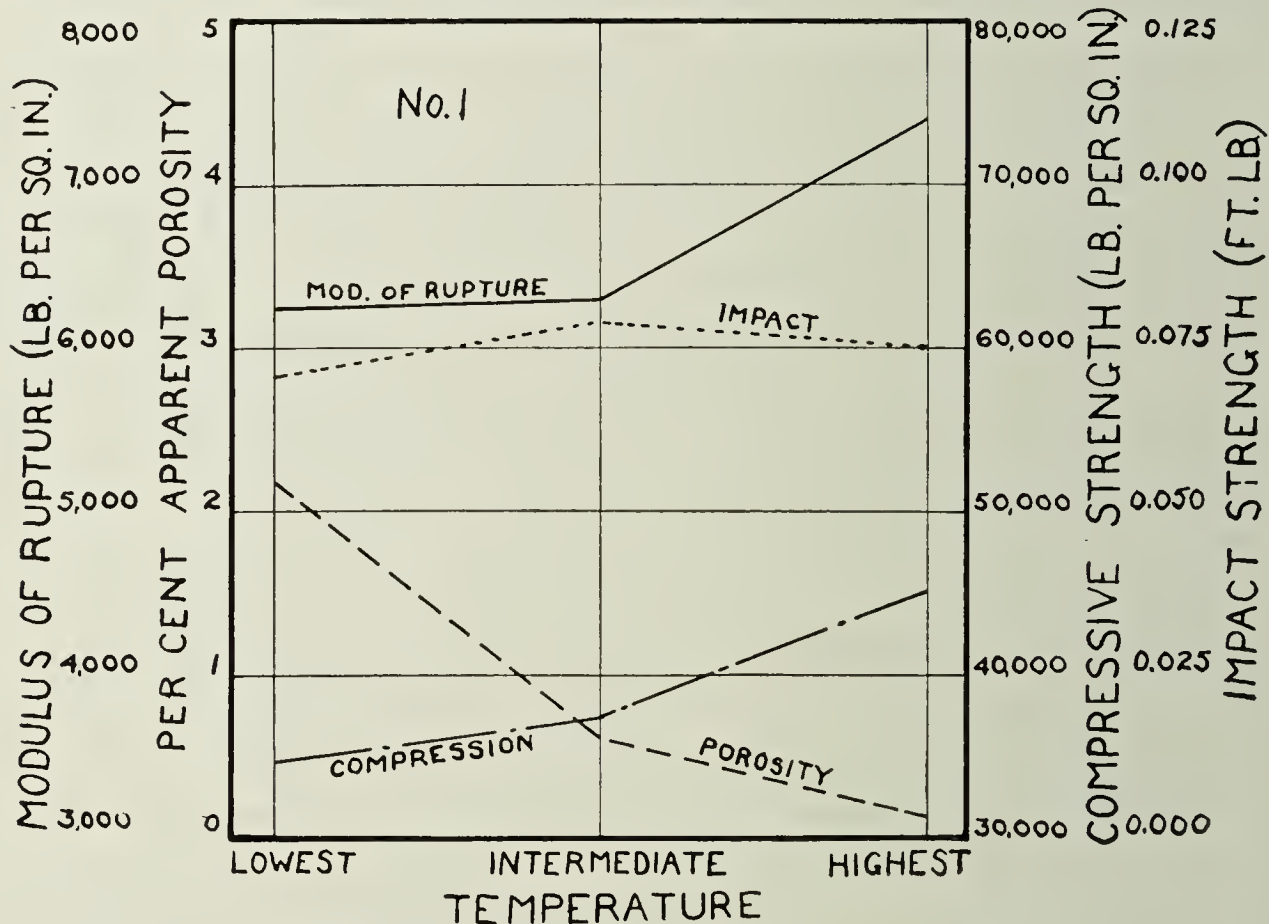


FIG. 5.—Results on body No. 1 fired in the pottery.

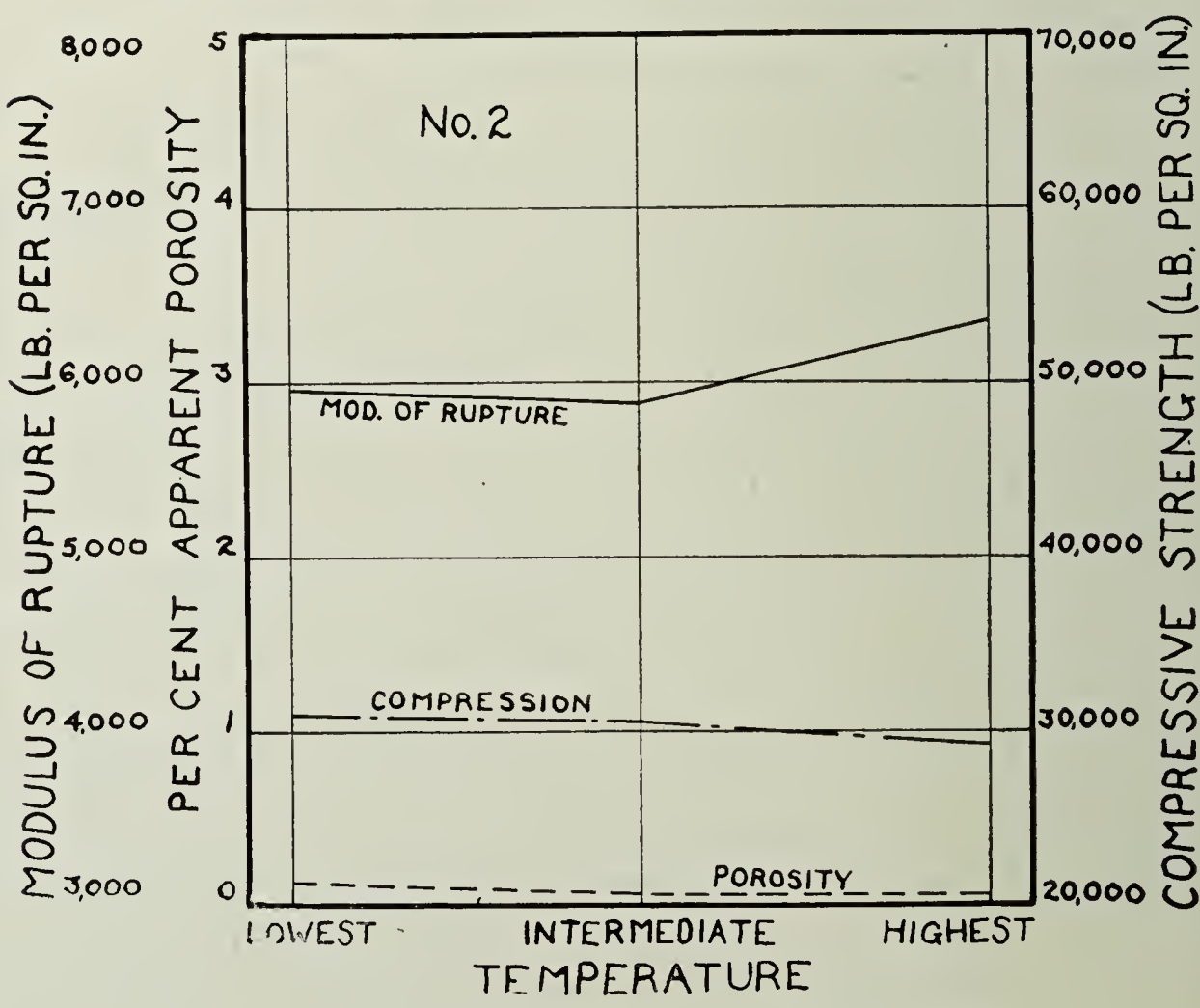


FIG. 6.—Results on body No. 2 fired in the pottery.

were decreasing, which might indicate that the maximum compressive and transverse strengths were reached at different conditions in the structure of the body.

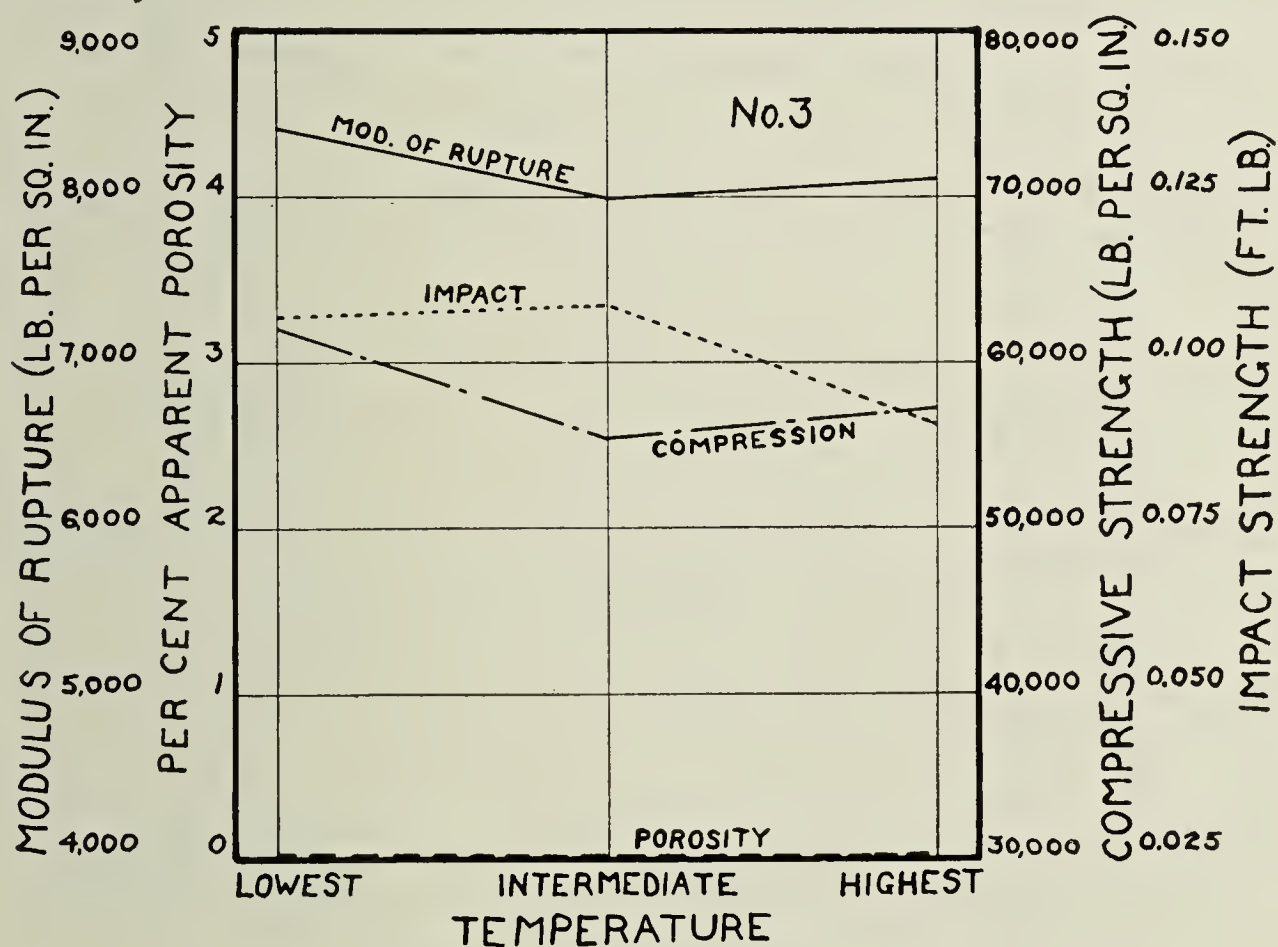


FIG. 7.—Results on body No. 3 fired in the pottery.

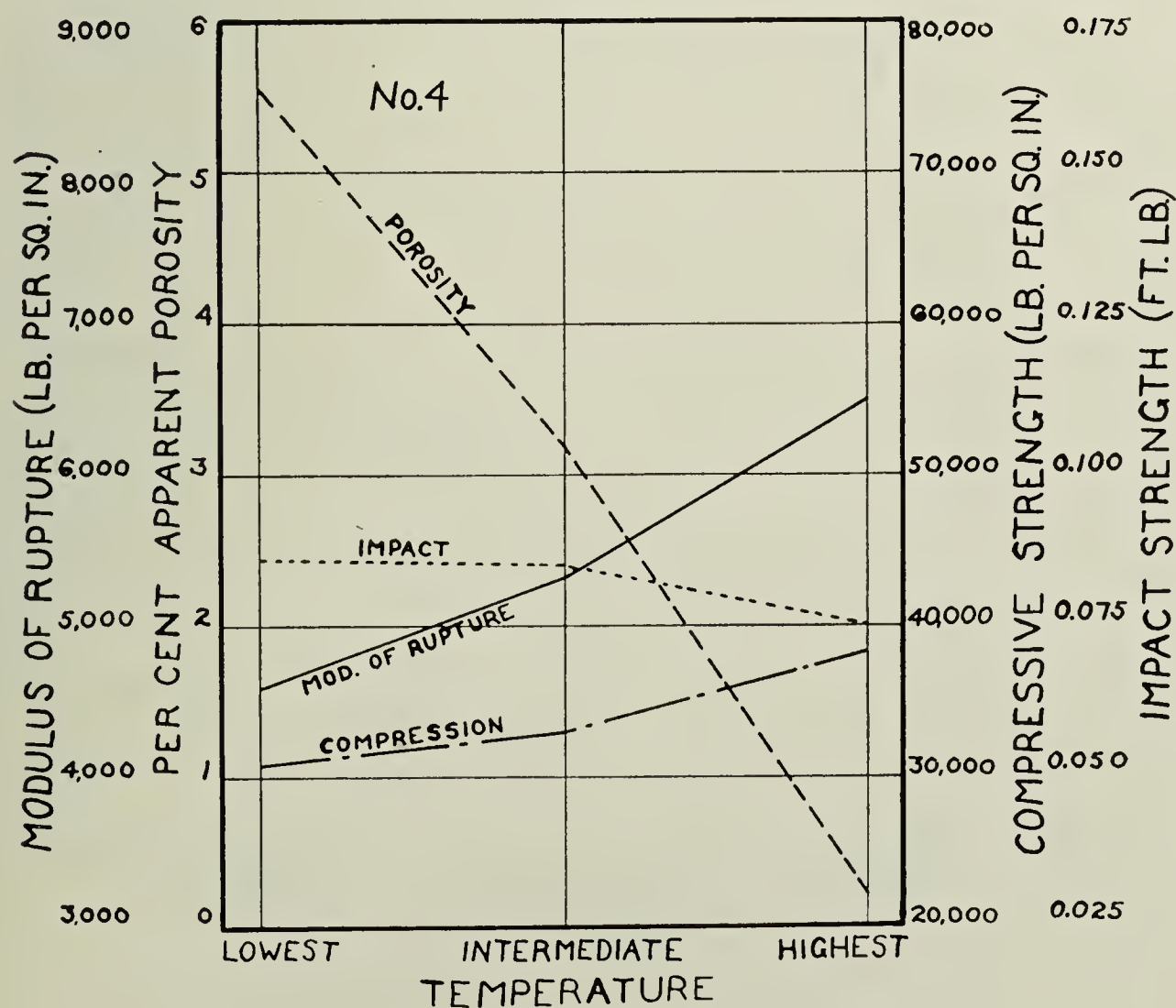


FIG. 8.—Results on body No. 4 fired in the pottery.

Figs. 5, 8, 10 and 13 show the effects of the underfiring of 1, 4 and 6 and the overfiring of 9 on the transverse, compressive and impact strength and their relation to the porosities of these bodies.

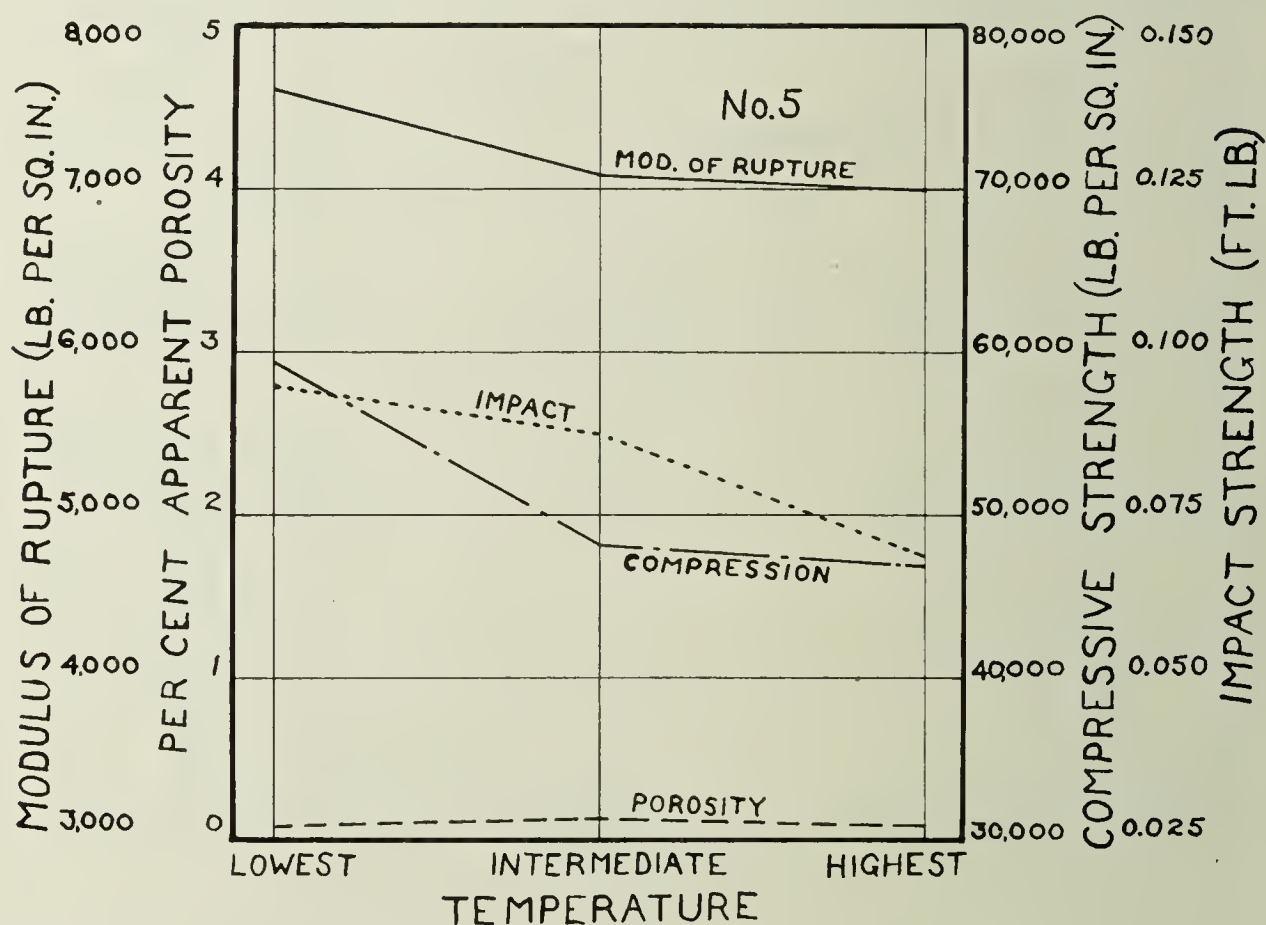


FIG. 9.—Results on body No. 5 fired in the pottery.

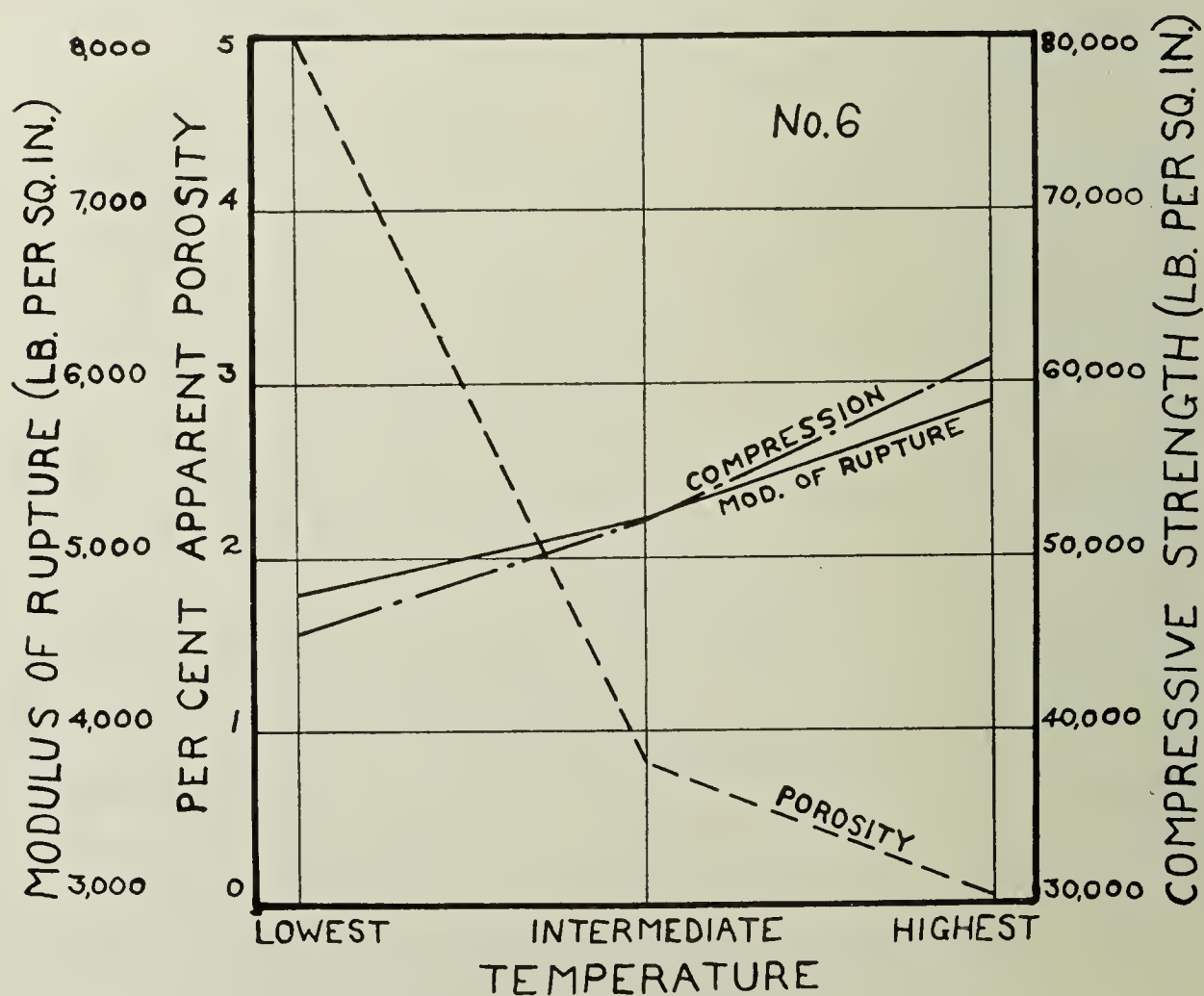


FIG. 10.—Results on body No. 6 fired in the pottery.

In general, the results of the work show that there are considerable differences in the physical properties of the body compositions in use, and furthermore that the kilns are often not finished at the point which would develop the maximum average strength throughout the kiln. In

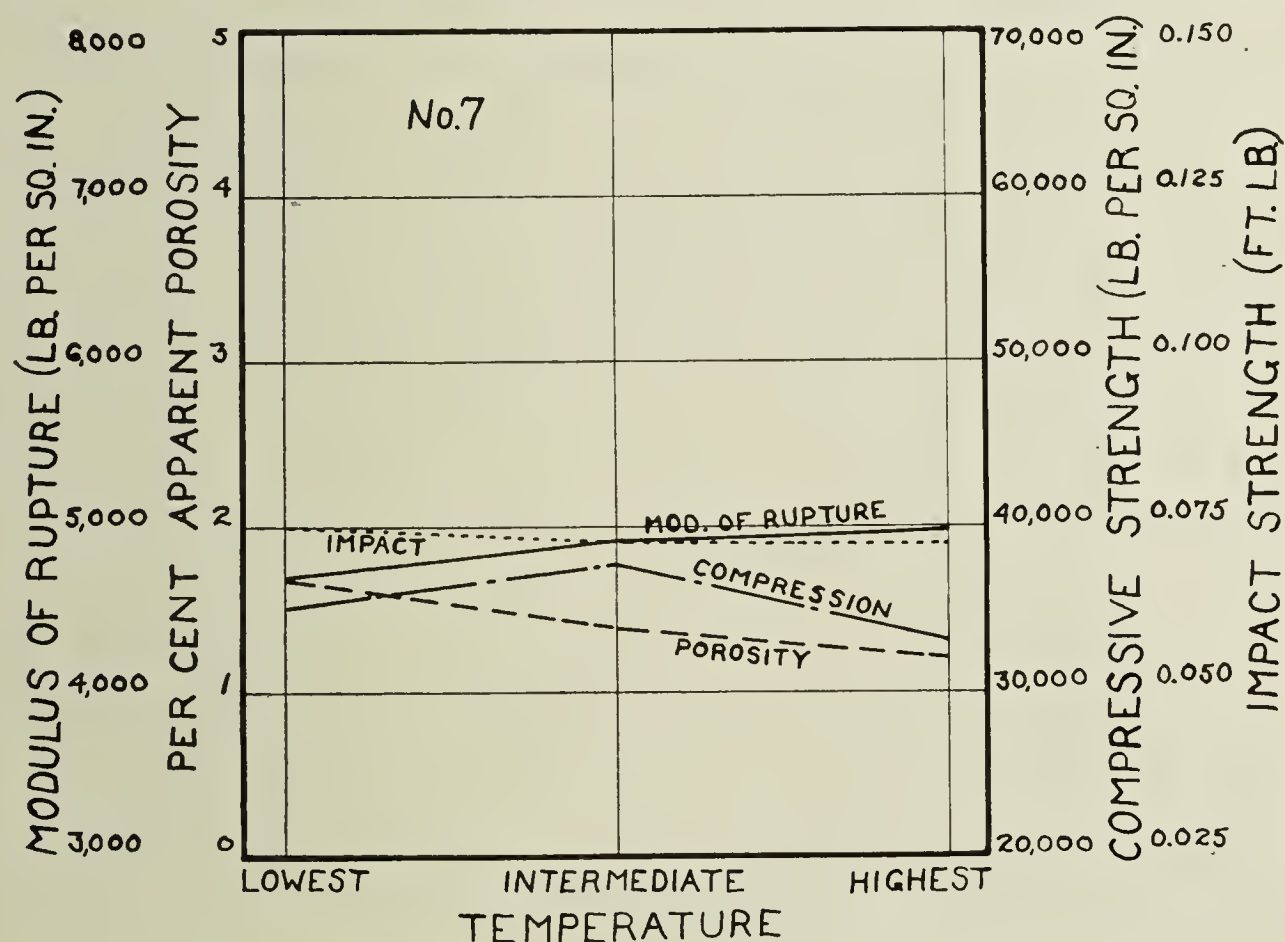


FIG. 11.—Results on body No. 7 fired in the pottery.

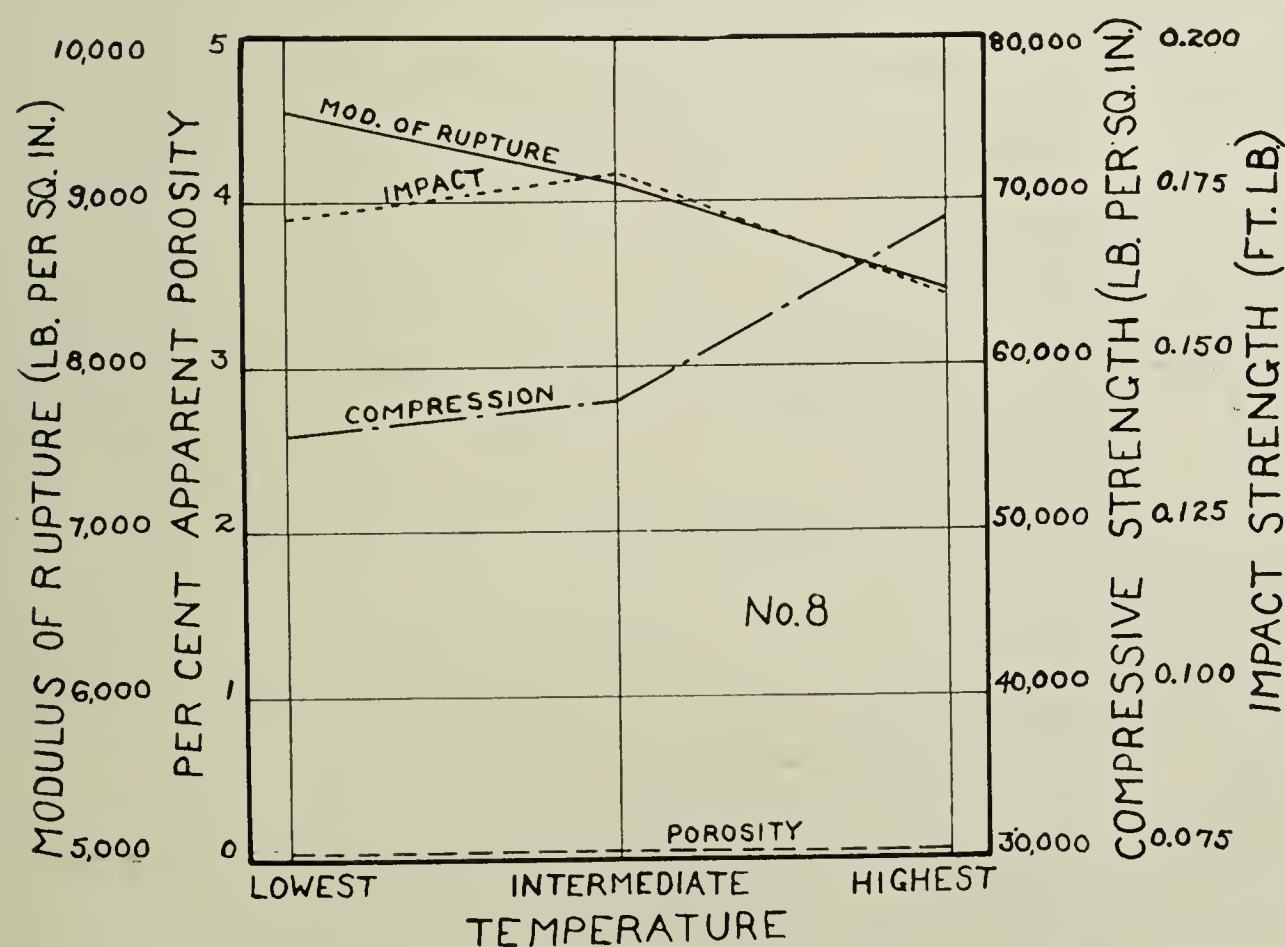


FIG. 12.—Results on body No. 8 fired in the pottery.

six of the ten kilns in which specimens were fired the pieces in the three positions in the kiln were evenly vitrified, which shows that the commercial kilns used can be fired to produce uniformly vitrified ware. That they are not always so finished is shown by the fact that three of the ten

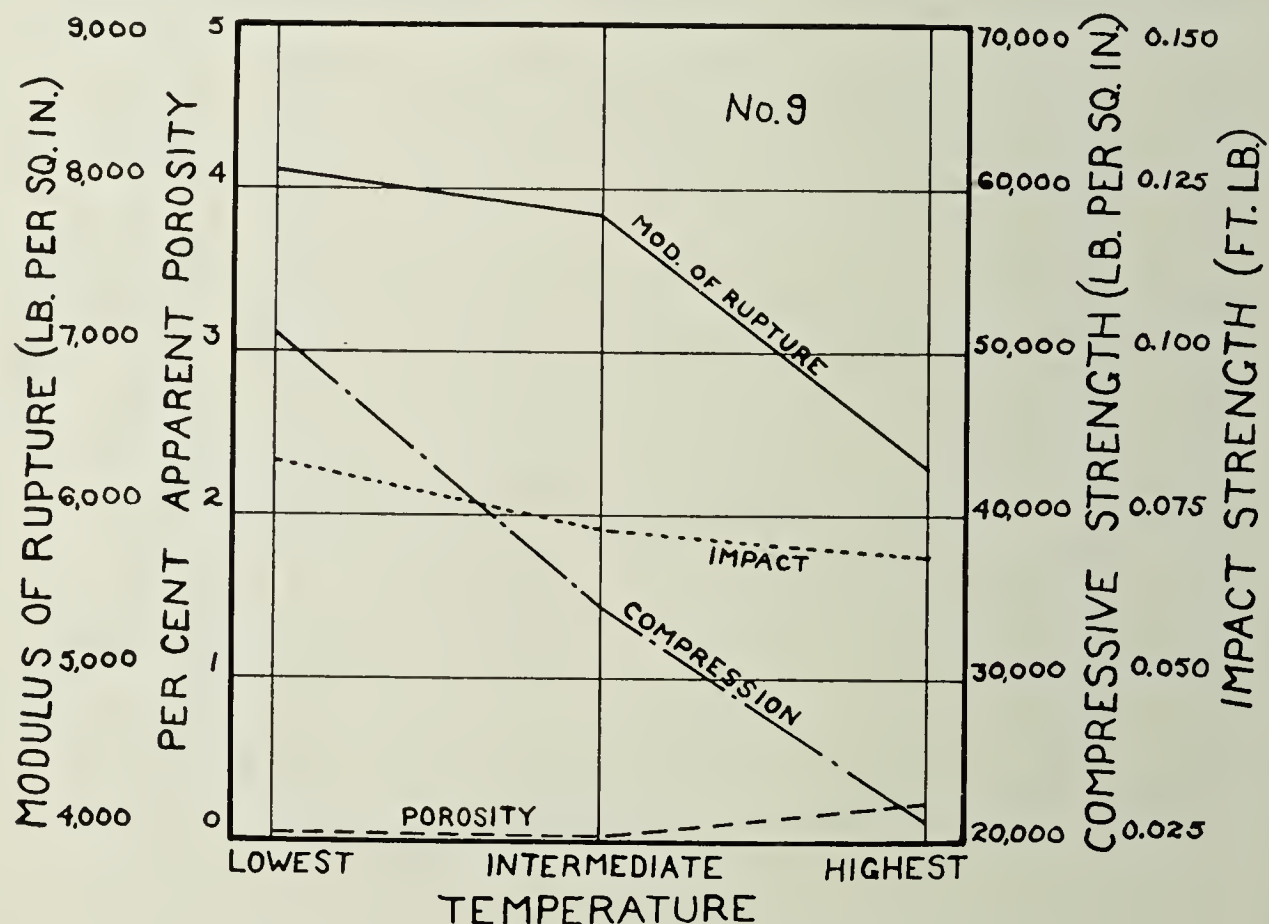


FIG. 13.—Results on body No. 9 fired in the pottery.

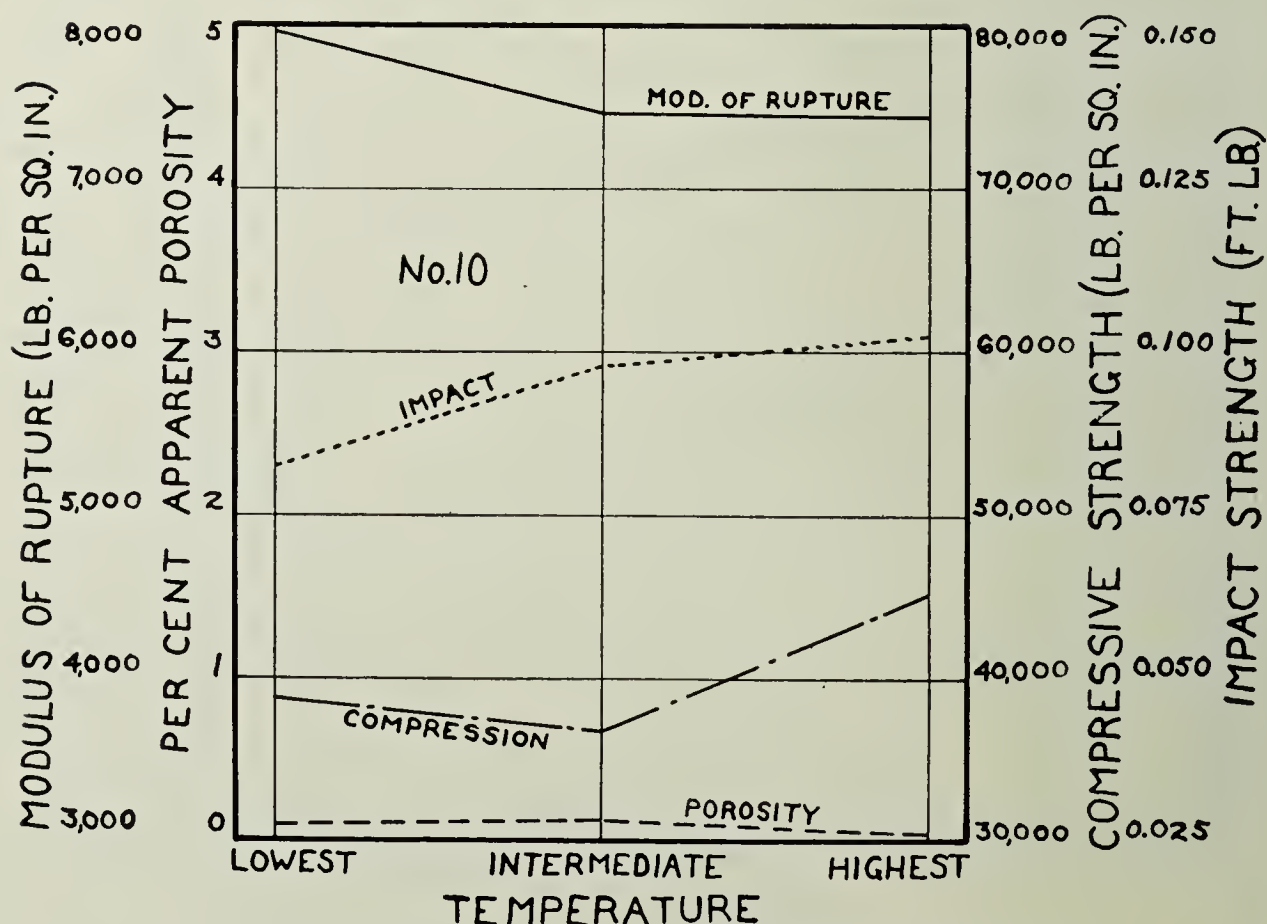


FIG. 14.—Results on body No. 10 fired in the pottery.

kilns were underfired and one overfired. The great importance of the proper firing of the bisque is apparent from a comparison of the strength of the underfired and overfired specimens with that of the same bodies when properly matured.

It would be advisable that tests of this kind be used more extensively in the industry in studying conditions in the kilns, body compositions and methods of body preparation. One of the most important requisites for hotel china, which is subjected to severe usage in restaurants, hotels, on railroads and steamships, is strength. Tests of this kind show the physical properties of a body itself exclusive of design with greater accuracy than tests of commercial shapes. The transverse strength, in

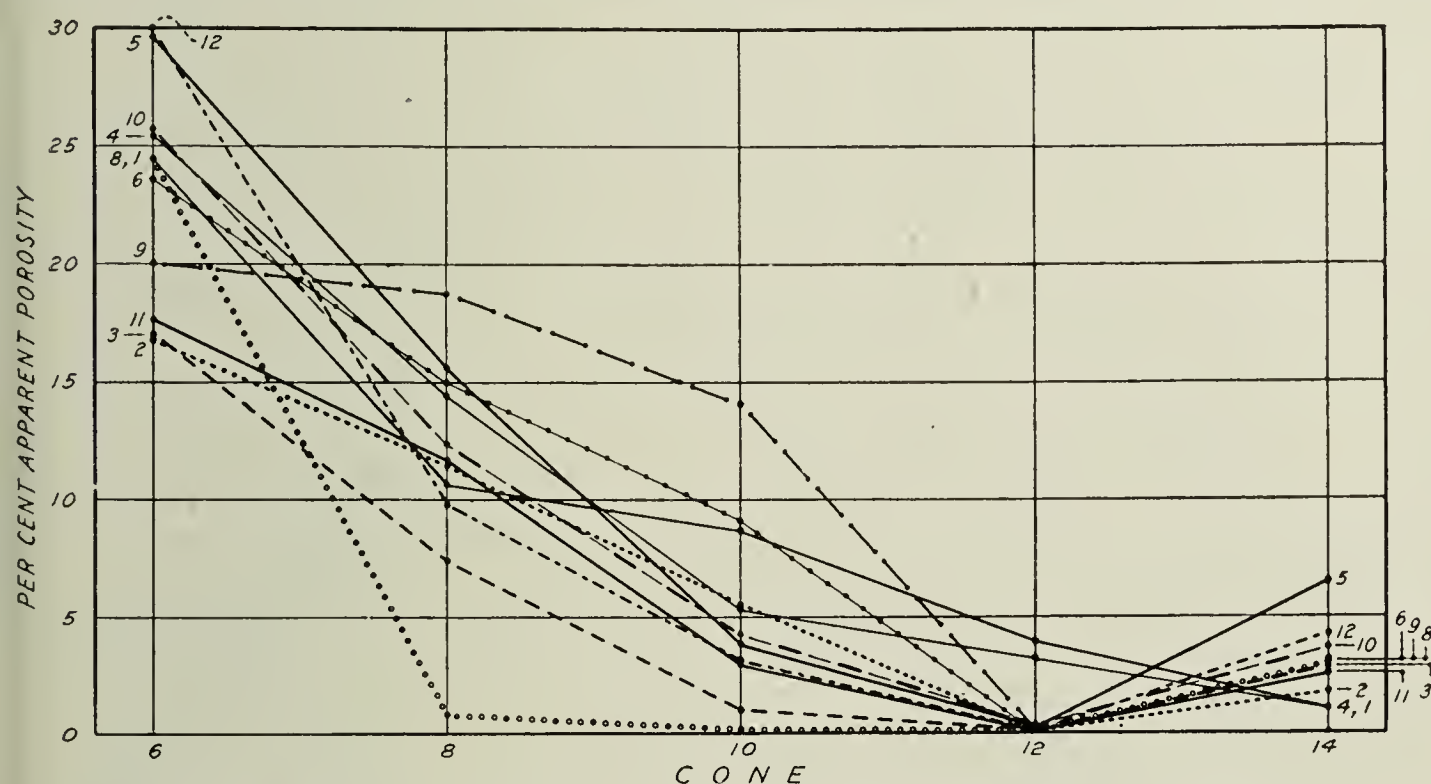


FIG. 15.—Per cent apparent porosity of bodies fired in the laboratory.

particular, can be determined easily, the results are significant and consistent, and the expense is not great. The use in the potteries of such tests in addition to the usual considerations of color and vitrification should result in more uniform bisque and stronger ware.

Results on Specimens Fired in the Laboratory

With the bodies fired at the Bureau of Standards two were included, Nos. 11 and 12, which were not in use at the time the potteries were visited, and one of the bodies fired in the pottery, No. 7, which was no longer being used, was omitted from this part of the investigation.

In studying the test results for the specimens fired in the laboratory it must be taken into consideration that the firing was done in a smaller kiln and at a more rapid rate of firing than the usual factory practice. This resulted in a slightly higher temperature being required to produce

a given condition in the body, and in only one case, No. 2, was as high a maximum strength obtained as in the larger pottery kiln. The numerical results are given in Table II.

The per cent apparent porosities of the eleven bodies fired to cones 6, 8, 10, 12 and 14 are shown graphically in Fig. 15. Considerable difference in the progress of vitrification of the specimens with increasing heat treatment is noted. The bodies may be divided into four general types in respect to firing behavior: namely, first, those vitrifying at from cone 8 to 10 and having a long vitrification range; second, those with porosity gradually reducing with increasing temperature and reaching a minimum in the neighborhood of cone 12; third, one which began vitrification later

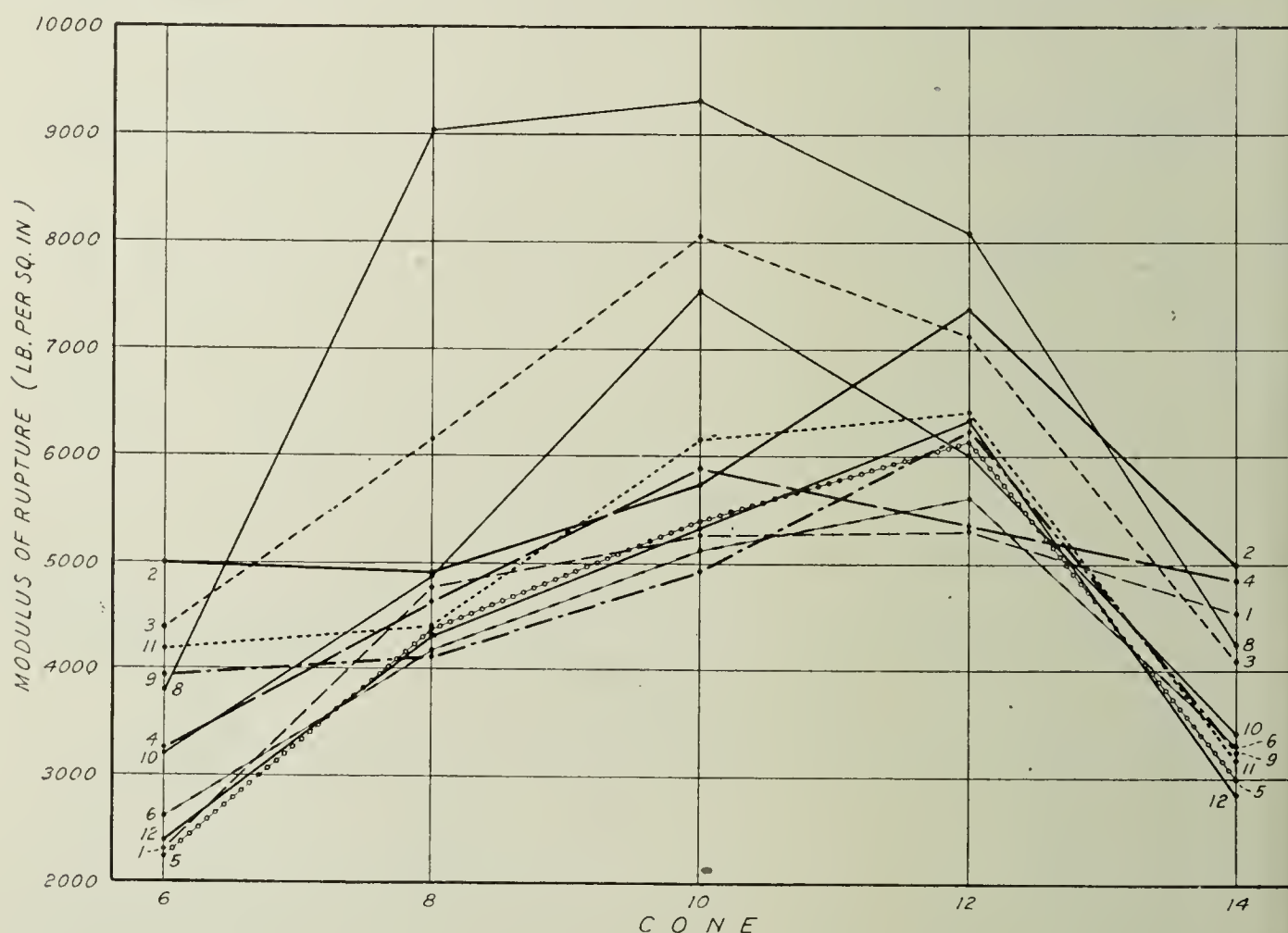


FIG. 16.—Transverse strength of specimens fired in laboratory.

than the preceding type and showed an abrupt decrease in porosity, vitrifying at the same temperature; fourth, bodies more refractory than those of the average composition and which, judging by the bulk specific gravities reached zero absorption between cones 12 and 14 in this kiln, over only a narrow range in temperature. Bodies 8 and 3 represent the first type. No. 8 was practically vitrified at cone 8 and had shown no signs of overfiring at cone 12. The second type includes six of the eleven bodies studied, 2, 5, 6, 10, 11 and 12. Body No. 9 was considerably behind the others in vitrification at cones 8 and 10, but decreased in porosity from 14.0% to 0.16% between cones 10 and 12. The fourth class, the

more refractory bodies, are represented by 1 and 4. The bulk specific gravities show that all of the bodies were overfired at cone 14.

The advantage to a potter of using a body with a vitrification behavior similar to that of No. 8 is obvious. Variations in heat treatment will have much less effect on the properties of a body with such a wide vitrification range, in producing ware of unsatisfactory quality than on those bodies which are properly vitrified during only a short range in temperature.

Fig. 16 shows the transverse strengths corresponding to the porosities just discussed. The development of the maximum transverse strength at cone 8 regardless of porosity which Schurecht¹ found to happen in

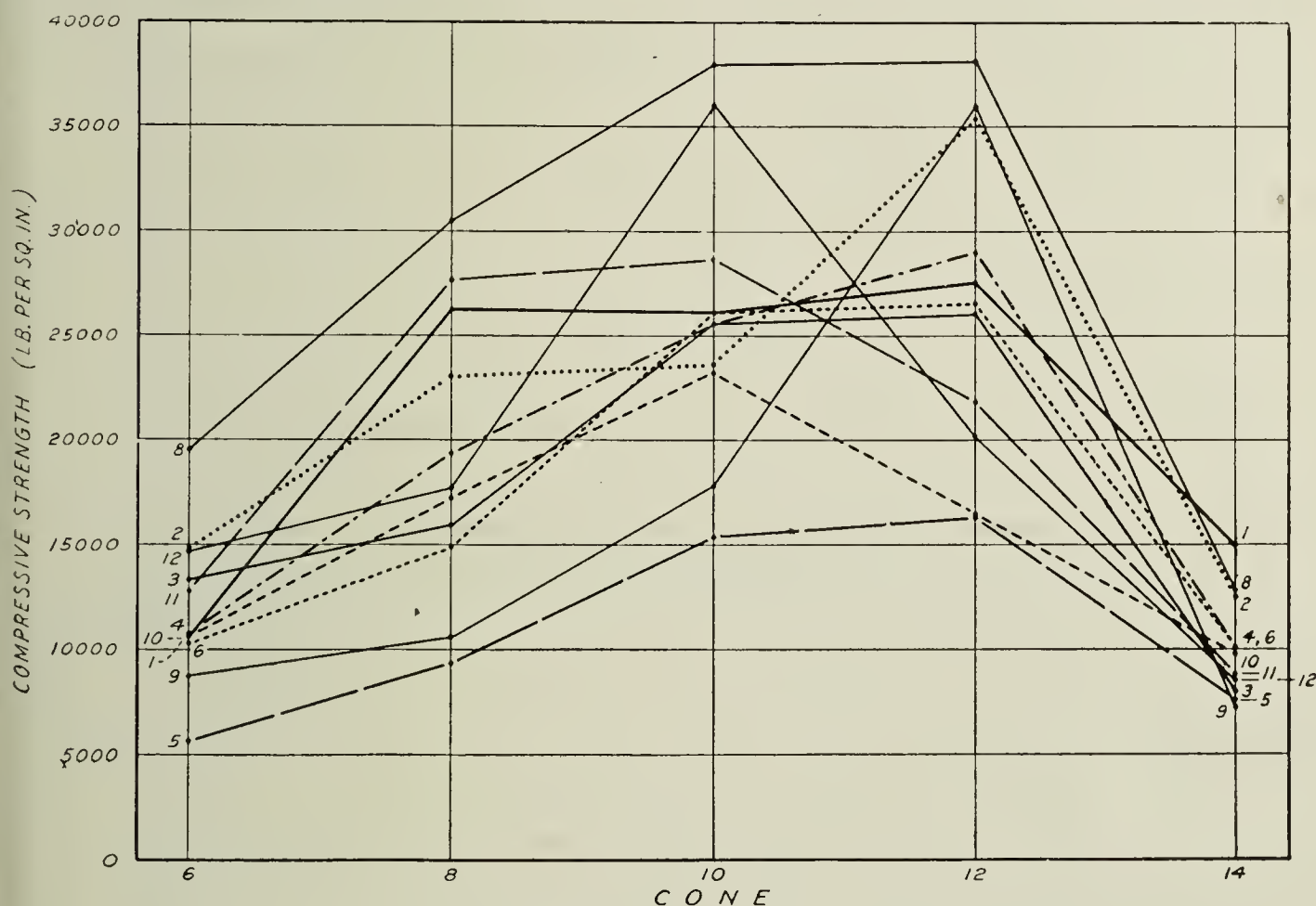


FIG. 17.—Compressive strength of specimens fired in laboratory.

stoneware clays did not occur in the compositions studied which were, of course, of an entirely different type. All of the eleven bodies studied reached their highest transverse strength near or prior to cone 12, and all suffered a great reduction in modulus of rupture between cones 12 and 14.

Seven of the eleven bodies attained their maximum transverse strength coincident with the minimum porosity obtained in these tests, Nos. 2, 5, 6, 9, 11 and 12 at cone 12, and No. 8 at cone 10. The greatest strength in No. 3 developed at cone 10 when the porosity was about 0.9 per cent, which is in the range of commercial vitrification for this type of bisque. Bodies 1, 4 and 10 developed their highest transverse strengths at porosities of 3.86, 5.33, and 4.03, respectively.

¹ H. G. Schurecht, *Jour. Amer. Ceram. Soc.*, 4 [5], 366 (1921).

The range in temperature of high transverse strength corresponded closely to the vitrification range, although some of the bodies did not show very great increases in modulus of rupture as vitrification was reached. Body No. 8 which had the widest vitrification range, also was high in transverse strength throughout the same range in temperature, and No. 9, which vitrified abruptly, showed an abrupt increase in strength at the same time.

As in the case of the specimens fired in the potteries, there was considerable variation in the maximum transverse strengths of the different bodies. The values varied from 9313 pounds per square inch for No. 8 to 5317 pounds per square inch for No. 1 and followed fairly closely the order in regard to the transverse strengths observed in the results on the specimens fired in the potteries.

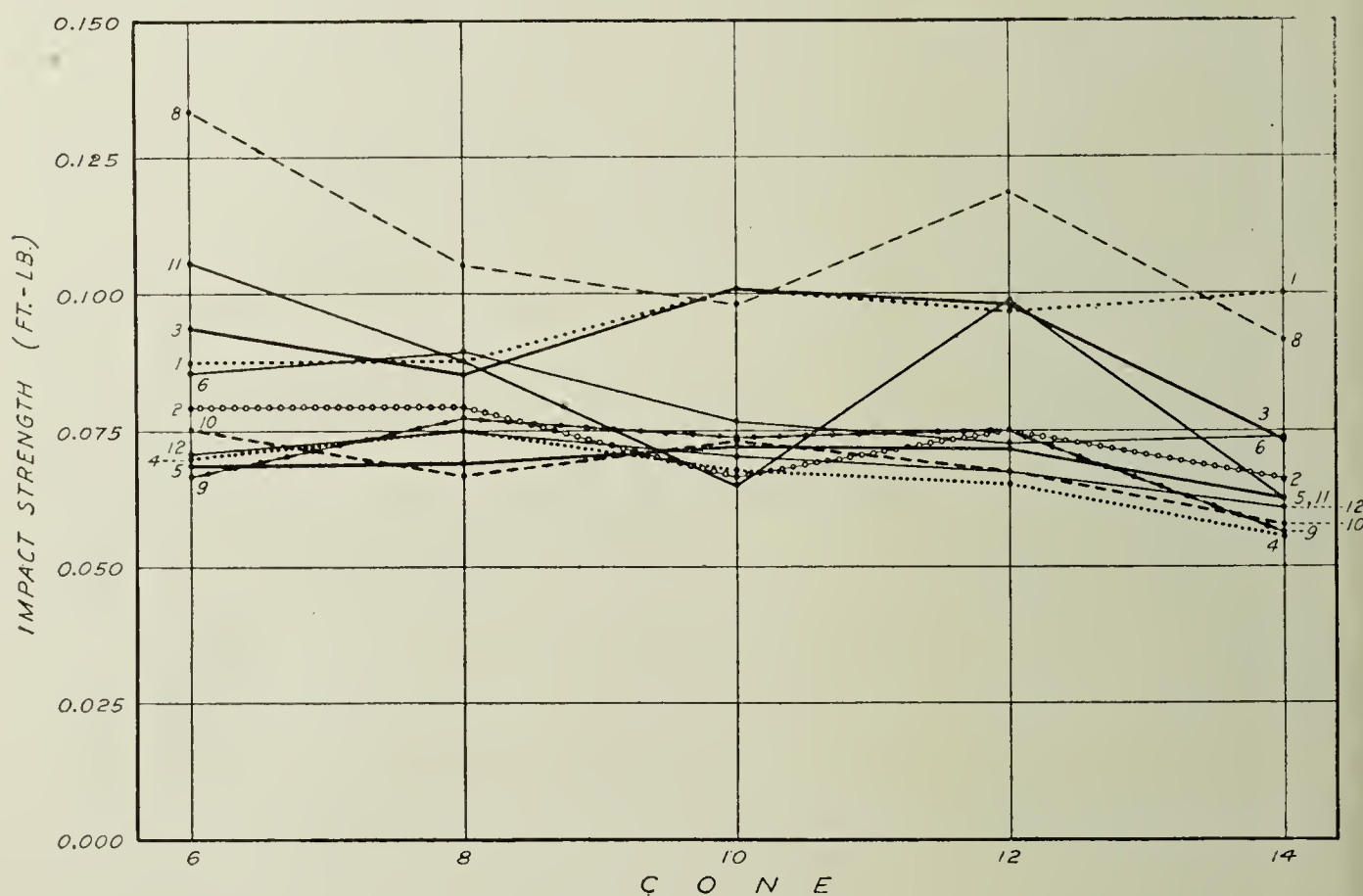


FIG. 18.—Results of impact tests on discs fired in the laboratory.

As in the compression tests previously described, the results obtained on the bodies fired in the smaller kiln, Fig. 17, were not as consistent as those for the moduli of rupture. According to expectations the greatest maximum compressive strength was that of No. 8. The loads per square inch causing failure of these specimens were very much lower than for the same bodies when given the slower firing and cooling in the pottery kilns.

The maximum compressive strength was found in bodies 2, 3, 5, 6, 8 and 9 when they were completely vitrified. Nos. 1 and 4 attained their maximum compressive strength at cone 12 and Nos. 10, 11 and 12 at cone 10, with porosities of from 3% to 4%.

In six instances the maximum compressive strength occurred at the same temperature as the highest modulus of rupture; in three cases it developed at a higher temperature, and in two bodies at a lower temperature.

The impact tests of the discs did not show consistent changes with

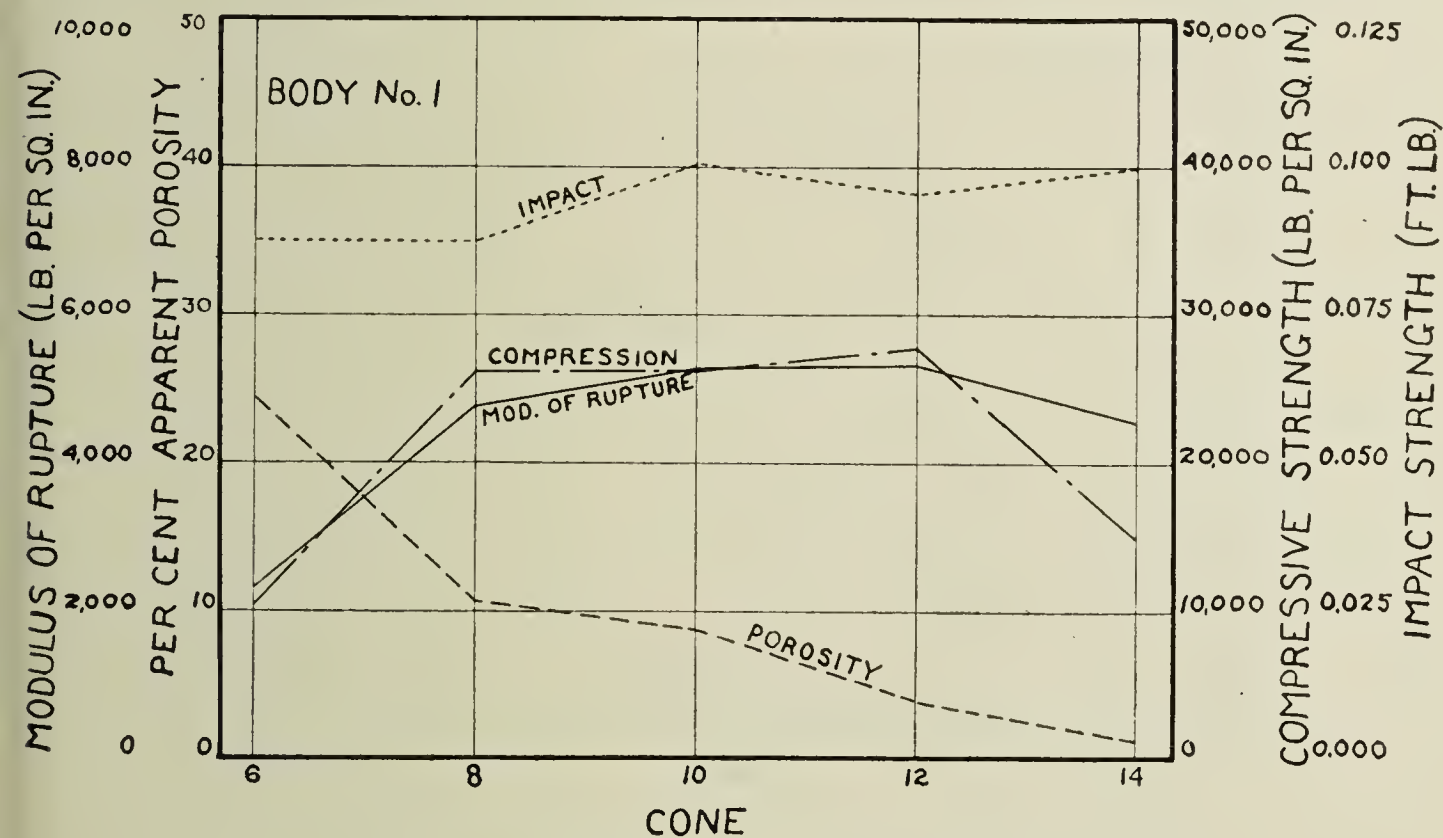


FIG. 19.—Results on body No. 1 fired in the laboratory.

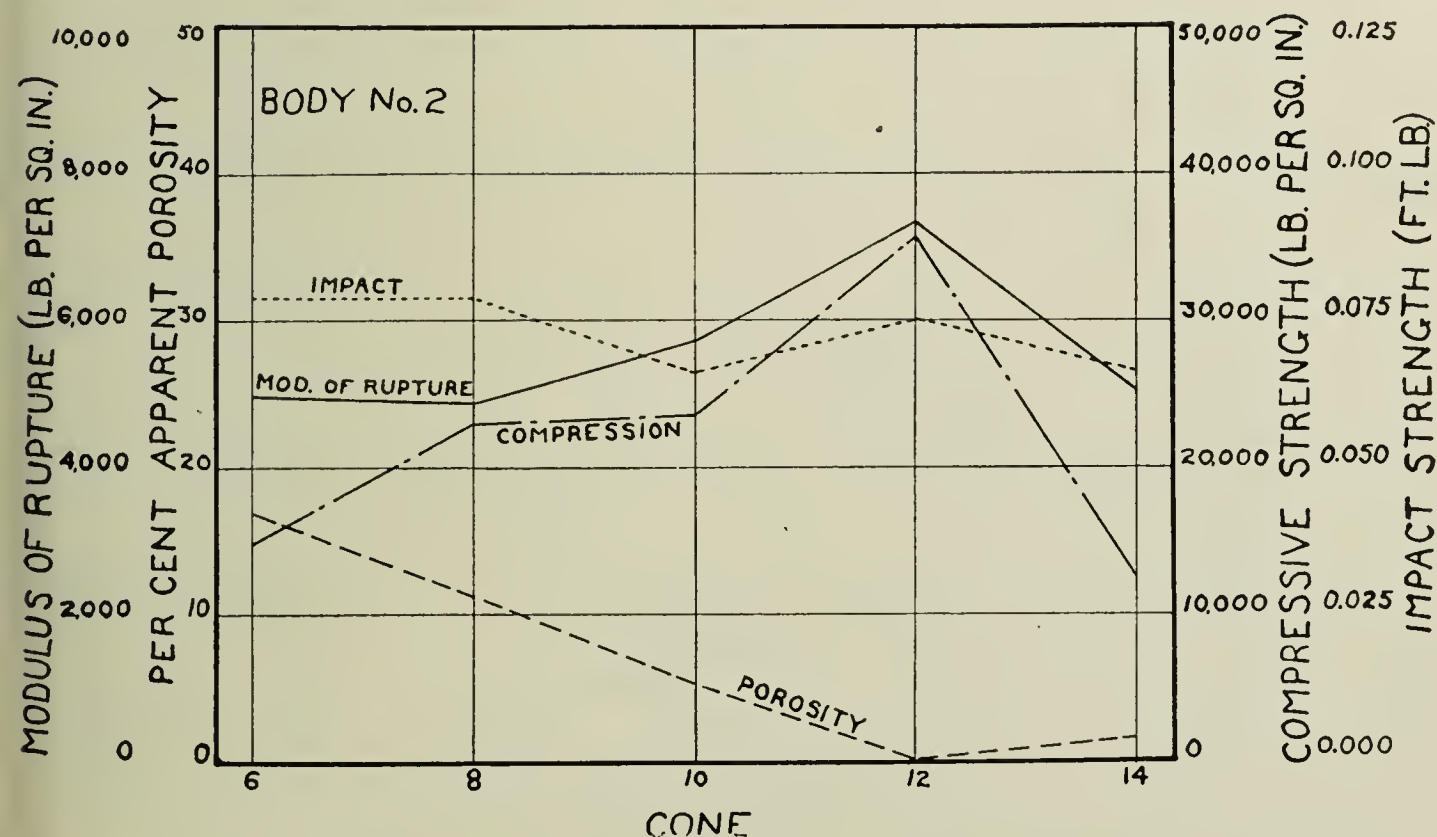


FIG. 20.—Results on body No. 2 fired in the laboratory.

increasing temperature except to indicate a reduction in the ability to withstand sudden blows as overfiring occurred. The greater strength of No. 8 appeared again in these results which are plotted in Fig. 18.

The change in transverse, compressive, and impact strengths and porosity with increasing temperature are shown collectively for each body in Figs. 19 to 29.

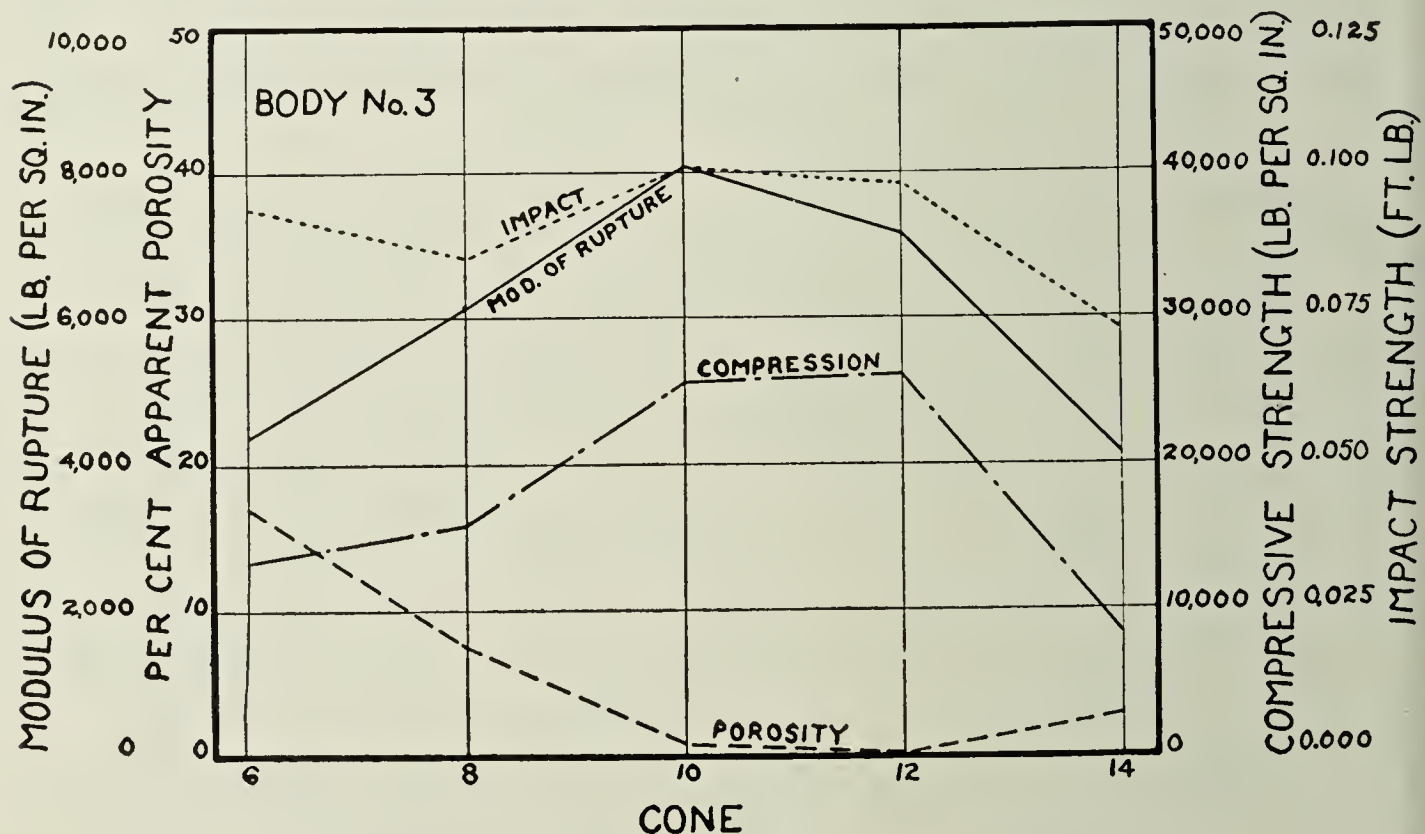


FIG. 21.—Results on body No. 3 fired in the laboratory.

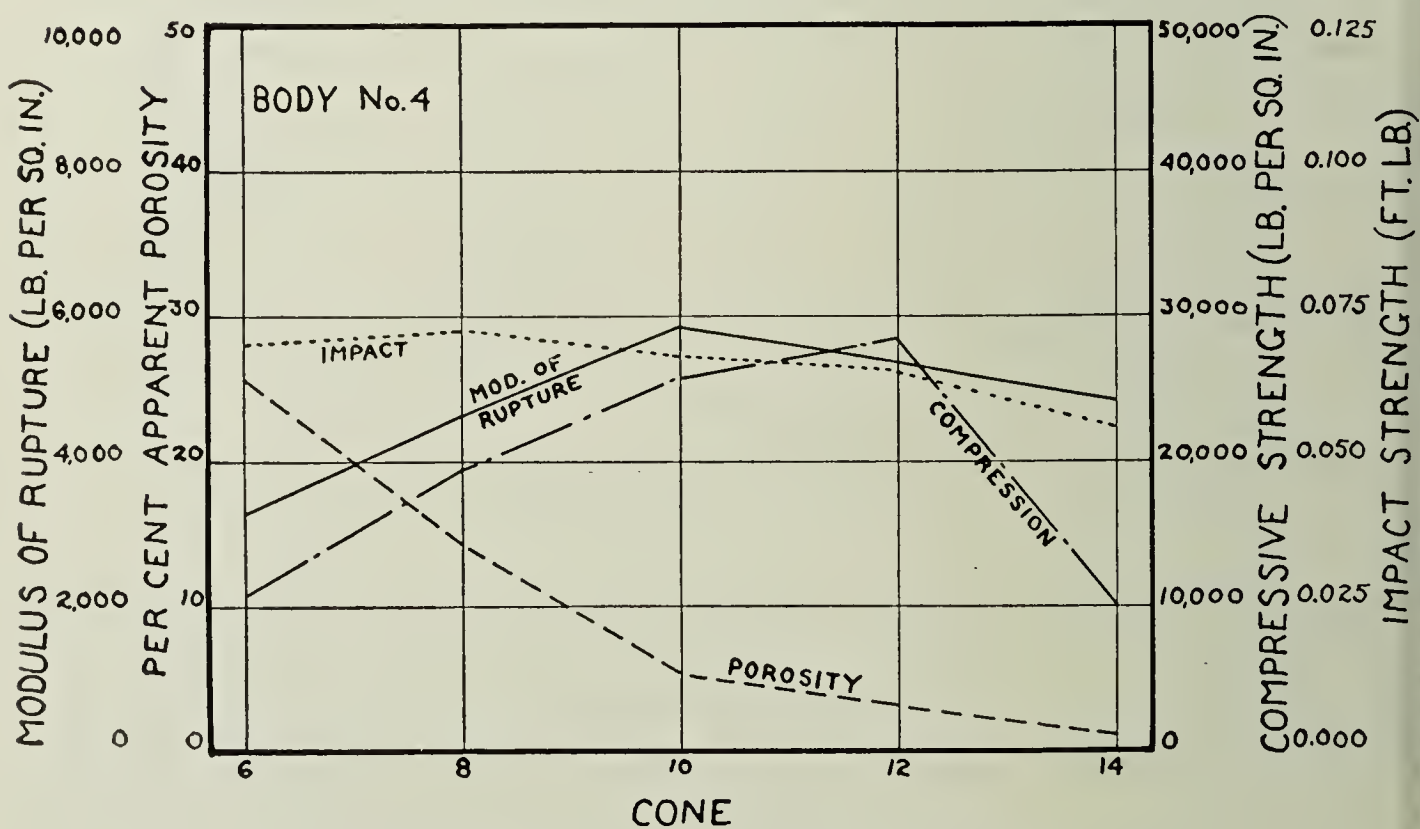


FIG. 22.—Results on body No. 4 fired in the laboratory.

Variations of two cones in firing treatment have a much greater effect on some commercial bodies of this type than on others. The range in temperature in which two of the bodies were vitrified and had high strength

was fairly wide. However, most of these commercial bodies became non-absorbent and attained their greatest strength within narrow limits in heat treatment, and in factory use require uniform firing conditions to produce bisque of near the same physical properties throughout a kiln.

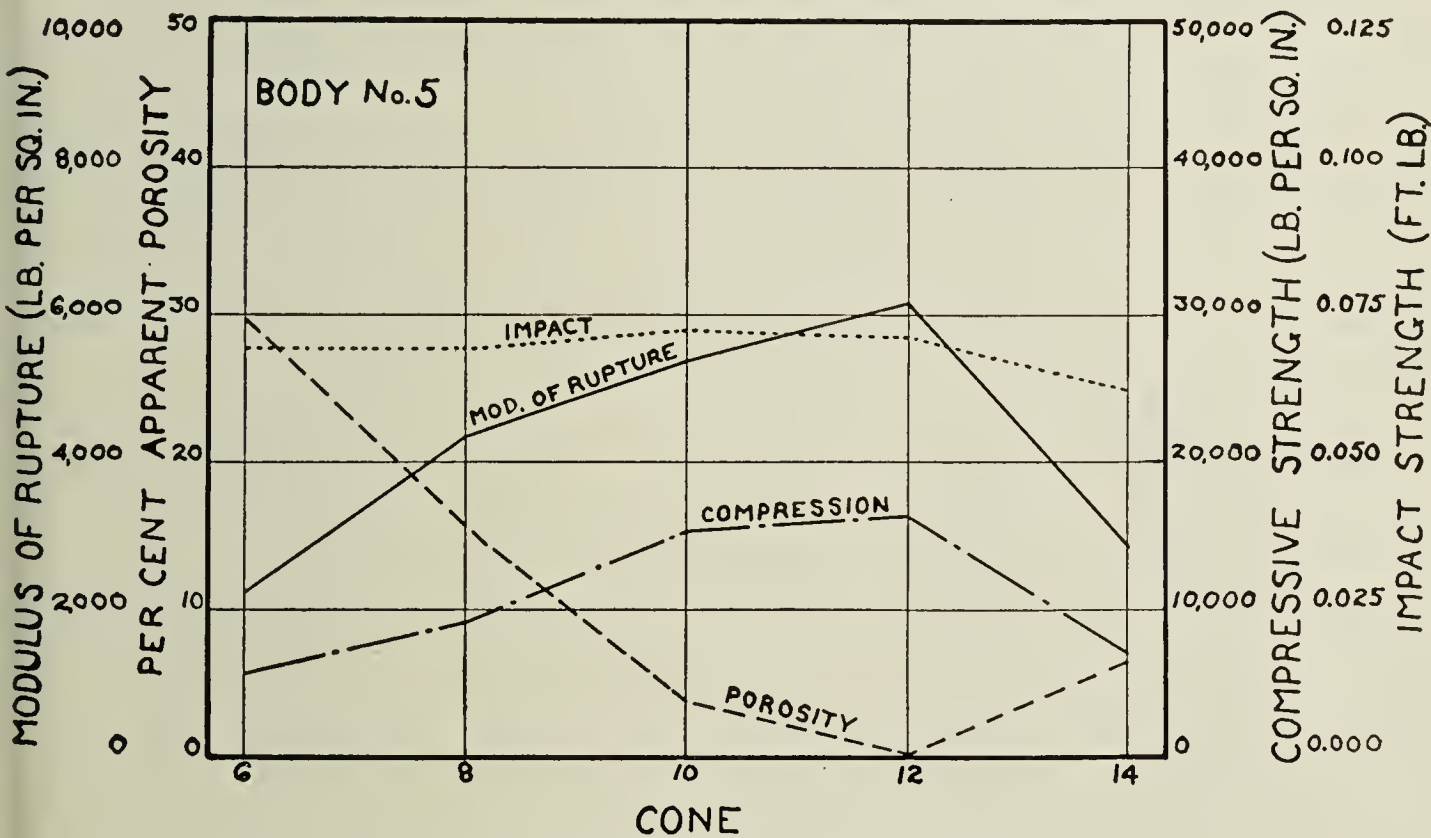


FIG. 23.—Results on body No. 5 fired in the laboratory.

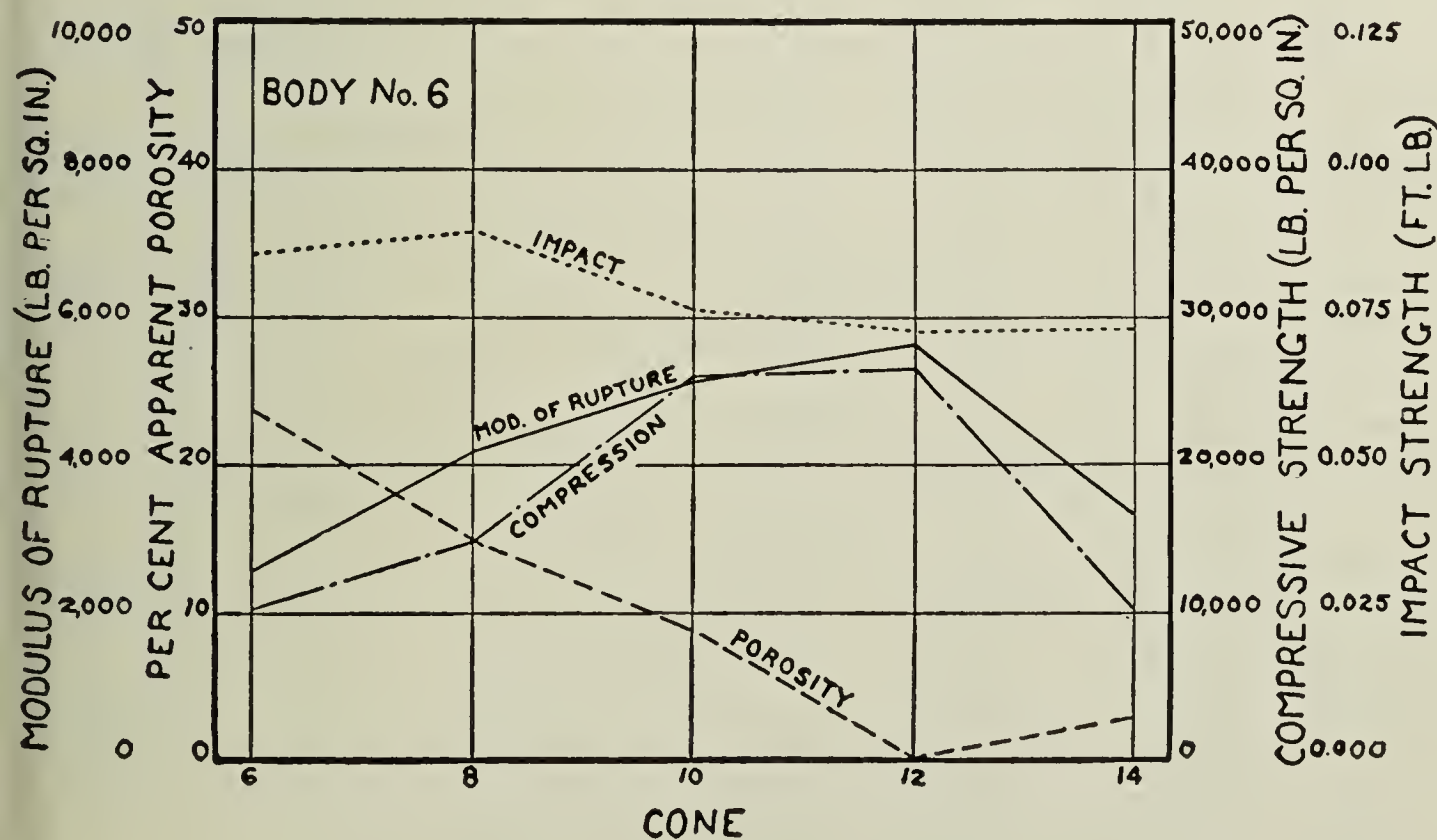


FIG. 24.—Results on body No. 6 fired in the laboratory.

The advantages of a body which will produce uniform ware in spite of the variations in kiln treatment are obvious, and the study of compositions from this standpoint by the potters is to be recommended.

Summary

In the ten pottery kilns studied, the bisque in six was uniformly vitrified. One kiln was slightly overfired and three were not fired quite hard enough to completely vitrify the specimens in the cooler parts of the kiln.

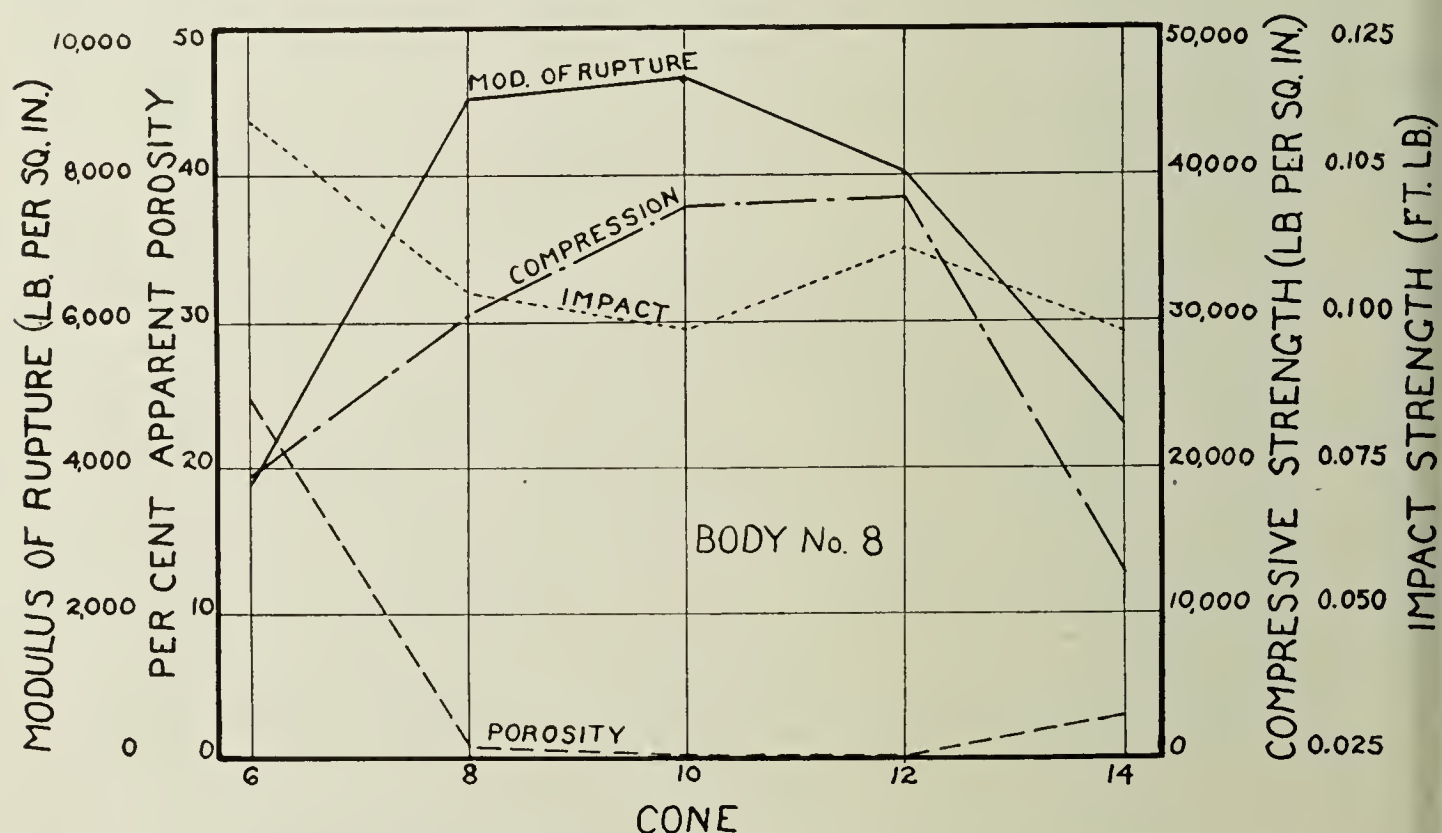


FIG. 25.—Results on body No. 8 fired in the laboratory.

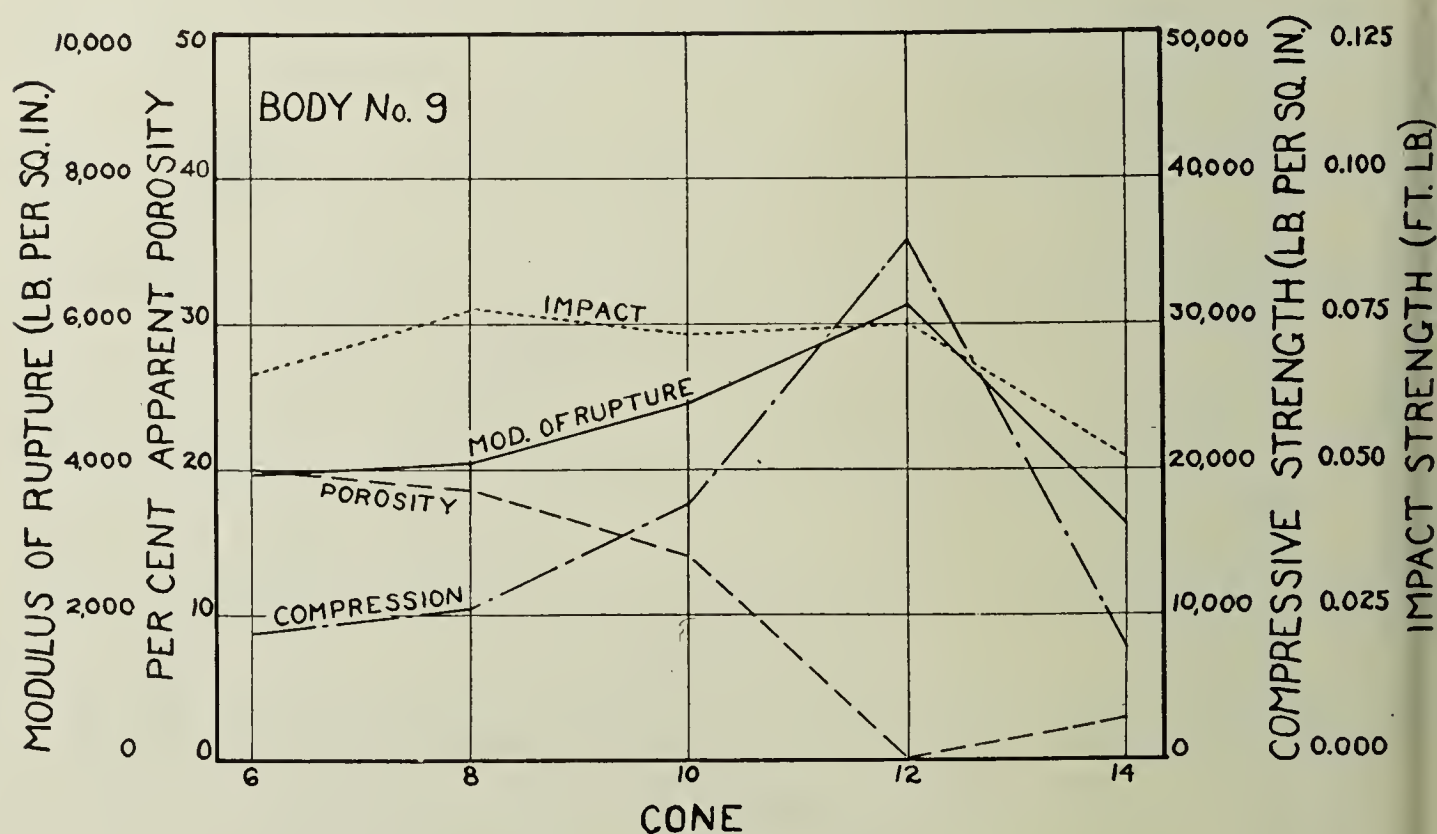


FIG. 26.—Results on body No. 9 fired in the laboratory.

The underfiring or overfiring of bodies of this type resulted in serious losses in strength when compared with that of the body properly vitrified.

While there was considerable difference in the maximum transverse,

compressive and impact strengths of the bodies, nearly all of them developed high strength when most advantageously fired.

The maximum strength existed over a narrower range in heat treatment than complete vitrification. The greater use in the potteries of tests of strength in the study of firing, compositions, and methods of body preparation would be of great help in raising the already high quality of American products.

The study of eleven bodies fired at temperatures of from cone 6 to cone 14 in the laboratory showed about the same differences in strength of the

TABLE I
RESULTS ON SPECIMENS FIRED IN POTTERIES

Number	Temperature	Bulk Specific Gravity	Per cent Absorption	Per cent Apparent Porosity	Modulus of Rupture (lbs. per sq. in.)	Compressive Strength (lbs. per sq. in.)	Impact Strength (ft. lbs.)	Average Thickness of Impact Specimens (inches)
1	H ¹	2.44	0.06	0.15	7403	45,130	0.0703	0.194
1	I	2.44	.26	.63	6310	37,490	.0791	.197
1	L	2.40	.91	2.18	6241	34,625	.0750	.199
2	H	2.35	.05	.11	6345	29,180	No discs made	
2	I	2.35	.05	.11	5864	30,380		
2	L	2.34	.06	.13	5960	30,820		
3	H	2.39	.00	.00	8118	57,290	.0910	.213
3	I	2.40	.00	.00	7985	55,440	.1089	.219
3	L	2.41	.00	.01	8402	62,125	.1071	.218
4	H	2.38	.08	.21	6486	38,170	.0750	.203
4	I	2.32	1.37	3.18	5306	32,805	.0850	.214
4	L	2.26	2.28	5.55	4586	30,750	.0859	.207
5	H	2.36	.04	.09	6994	46,970	.0734	.200
5	I	2.37	.05	.13	7070	48,125	.0875	.203
5	L	2.38	.05	.09	7604	59,440	.0946	.197
6	H	2.35	.02	.04	5896	61,320		
6	I	2.32	.35	.80	5231	52,050	No discs made	
6	L	2.26	2.22	5.01	4786	45,560		
7	H	2.37	.51	1.20	4975	33,080	.0725	.205
7	I	2.37	.59	1.38	4908	37,560	.0725	.205
7	L	2.36	.71	1.67	4693	34,090	.0750	.206
8	H	2.37	.02	.04	8453	68,930	.1604	.250
8	I	2.41	.02	.05	9105	57,950	.1791	.249
8	L	2.42	.02	.04	9444	55,780	.1725	.232
9	H	2.32	.11	.24	6296	21,260	.0688	.191
9	I	2.40	.01	.03	7830	34,490	.0729	.195
9	L	2.39	.02	.05	8106	51,080	.0833	.199
10	H	2.41	.02	.04	7456	45,090	.1025	.212
10	I	2.41	.06	.13	7462	38,170	.0979	.200
10	L	2.42	.04	.09	7967	36,650	.0825	.195

¹ The letters H, I, and L denote highest, intermediate, and lowest, respectively.

TABLE II
RESULTS ON SPECIMENS FIRED IN LABORATORY

Number	Cone	Bulk Specific Gravity	Percent Absorption	Per cent Apparent Porosity	Modulus of Rupture (lbs. per sq. in.)	Compressive Strength (lbs. per sq. in.)	Impact Strength (ft. lbs.)	Average Thickness of Impact Specimens (inches)
1	6	1.93	12.67	24.34	2298	10,450	0.0875	0.220
1	8	2.23	4.73	10.59	4755	26,150	.0875	.224
1	10	2.30	3.78	8.72	5267	26,000	.1008	.225
1	12	2.40	1.58	3.86	5317	27,630	.0969	.222
1	14	2.12	.58	1.17	4557	14,920	.1000	.232
2	6	2.10	8.00	16.83	4987	14,820	.0792	.203
2	8	2.18	5.29	11.44	4872	23,080	.0792	.209
2	10	2.33	2.34	5.45	5717	23,650	.0663	.216
2	12	2.42	.02	.06	7363	35,560	.0750	.198
2	14	2.05	.91	1.86	5018	12,505	.0662	.212
3	6	2.07	6.58	16.94	4376	13,280	.0937	.200
3	8	2.33	3.23	7.37	6127	15,880	.0850	.174
3	10	2.36	.38	.89	8035	25,570	.1008	.171
3	12	2.36	.03	.08	7120	26,180	.0979	.170
3	14	1.94	1.52	2.90	4130	8,080	.0732	.195
4	6	1.91	13.99	25.51	3258	10,680	.0700	.200
4	8	2.13	6.73	14.32	4626	19,360	.0750	.184
4	10	2.33	2.28	5.33	5851	25,570	.0680	.178
4	12	2.35	1.35	3.16	5347	28,890	.0653	.175
4	14	2.10	.55	1.12	4862	10,110	.0555	.170
5	6	1.79	16.34	29.72	2249	5,620	.0688	.204
5	8	2.10	7.46	15.57	4358	9,204	.0688	.174
5	10	2.30	1.67	3.78	5374	15,270	.0725	.184
5	12	2.33	.06	.13	6154	16,370	.0714	.183
5	14	1.84	3.21	6.50	2897	7,710	.0625	.218
6	6	1.92	12.38	23.64	2600	10,250	.0854	.248
6	8	2.11	6.40	14.90	4161	14,850	.0896	.230
6	10	2.25	3.98	8.98	5108	26,000	.0764	.214
6	12	2.33	.07	.17	5614	26,630	.0725	.210
6	14	1.98	1.12	3.03	3333	10,064	.0734	.239
8	6	1.93	12.29	24.48	3794	19,450	.1344	.258
8	8	2.39	.33	.79	9033	30,450	.1050	.198
8	10	2.39	.02	.04	9313	37,860	.0979	.201
8	12	2.38	.02	.05	8008	38,380	.1188	.210
8	14	1.93	1.52	2.95	4283	12,560	.0919	.257
9	6	2.03	9.81	19.97	3937	8,730	.0666	.190
9	8	2.07	8.95	18.62	4107	10,500	.0775	.212
9	10	2.17	6.47	14.00	4911	17,700	.0734	.182
9	12	2.35	.07	.16	6253	35,880	.0750	.170
9	14	1.98	1.51	2.81	3239	7,680	.0521	.190
10	6	1.88	13.51	25.61	3217	10,510	.0750	.199
10	8	2.18	6.16	12.28	4896	17,180	.0666	.185
10	10	2.35	1.71	4.03	7521	23,171	.0725	.170

10	12	2.36	.14	.34	6037	16,460	.0675	.177
10	14	1.93	1.93	3.71	3425	9,990	.0575	.201
11	6	2.03	8.68	17.59	4192	12,730	.1054	.255
11	8	2.18	4.87	11.59	4376	27,700	.0875	.216
11	10	2.33	1.24	2.89	6121	28,600	.0650	.176
11	12	2.36	.10	.24	6418	21,920	.0986	.237
11	14	1.95	1.37	2.66	3208	8,990	.0625	.216
12	6	1.78	17.05	30.00	2374	14,730	.0719	.212
12	8	2.24	4.36	9.74	4280	17,680	.0750	.201
12	10	2.34	1.25	2.95	5279	36,150	.0700	.174
12	12	2.32	.06	.15	6350	20,220	.0675	.180
12	14	1.86	2.26	4.22	2881	11,120	.0607	.212

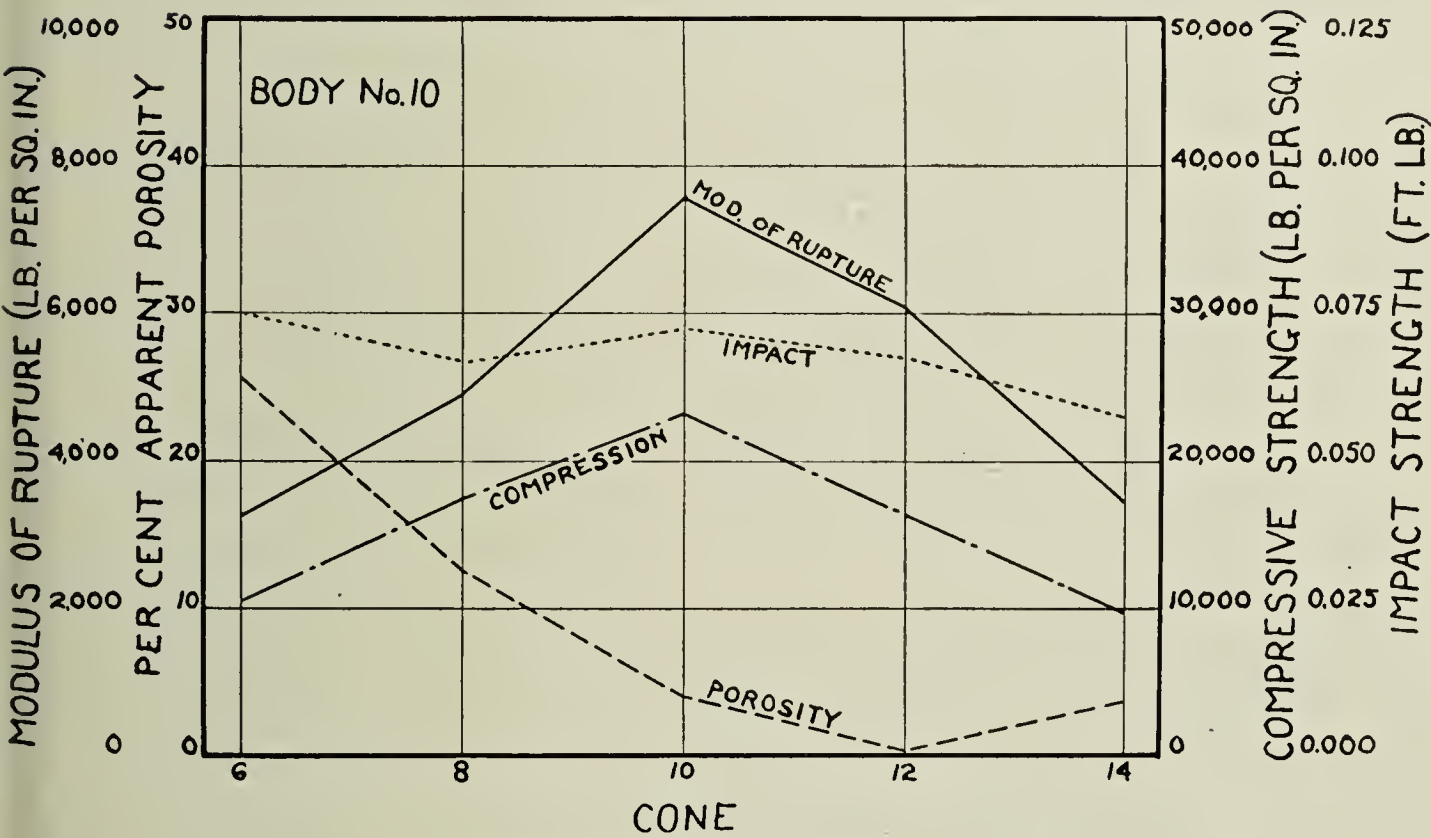


FIG. 27.—Results on body No. 10 fired in the laboratory.

bodies as the tests on the specimens fired in the pottery kilns. In one body only as high maximum strength was found in the specimens fired in the small kiln as in those fired in the factories.

In most cases the maximum strength was developed coincident with vitrification, and in all the bodies it occurred near or prior to cone 12.

Impact tests on discs did not show any consistent differences in impact strength with increasing temperature except to show a reduction with overfiring.

There was considerable difference in the bodies studied in regard to the temperature range over which they were vitrified and of greatest strength. While two of the bodies were excellent in this respect, the remainder were vitrified and of high strength only through a narrow range of cones.

The study of compositions and methods of body preparation from this standpoint is desirable. The Bureau of Standards is planning a study of this kind on porcelain bodies.

ACKNOWLEDGMENTS: The author wishes to thank Mr. C. E. Jackson, chairman of the American Vitified China Manufacturers Association, and the members of the

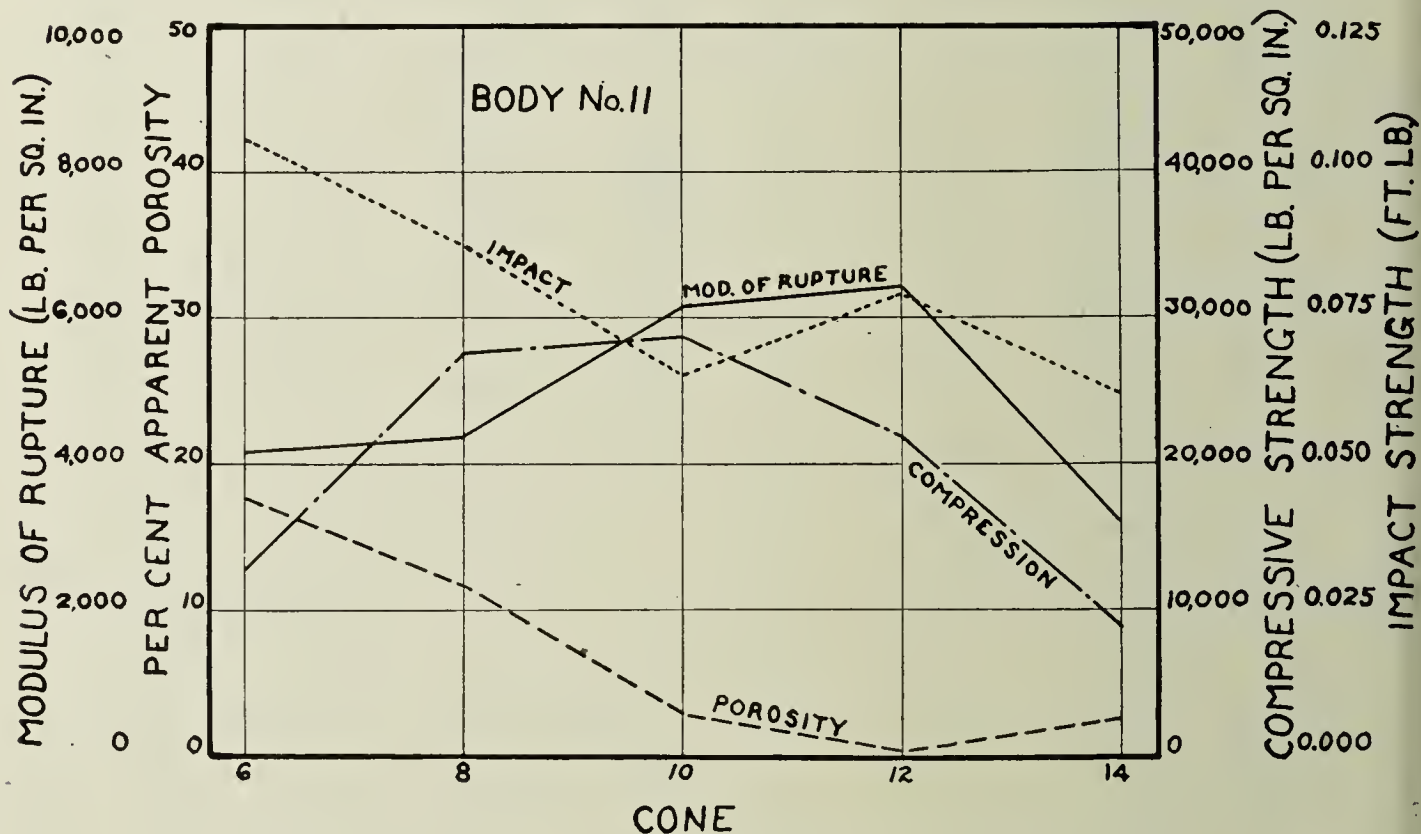


FIG. 28.—Results on body No. 11 fired in the laboratory.

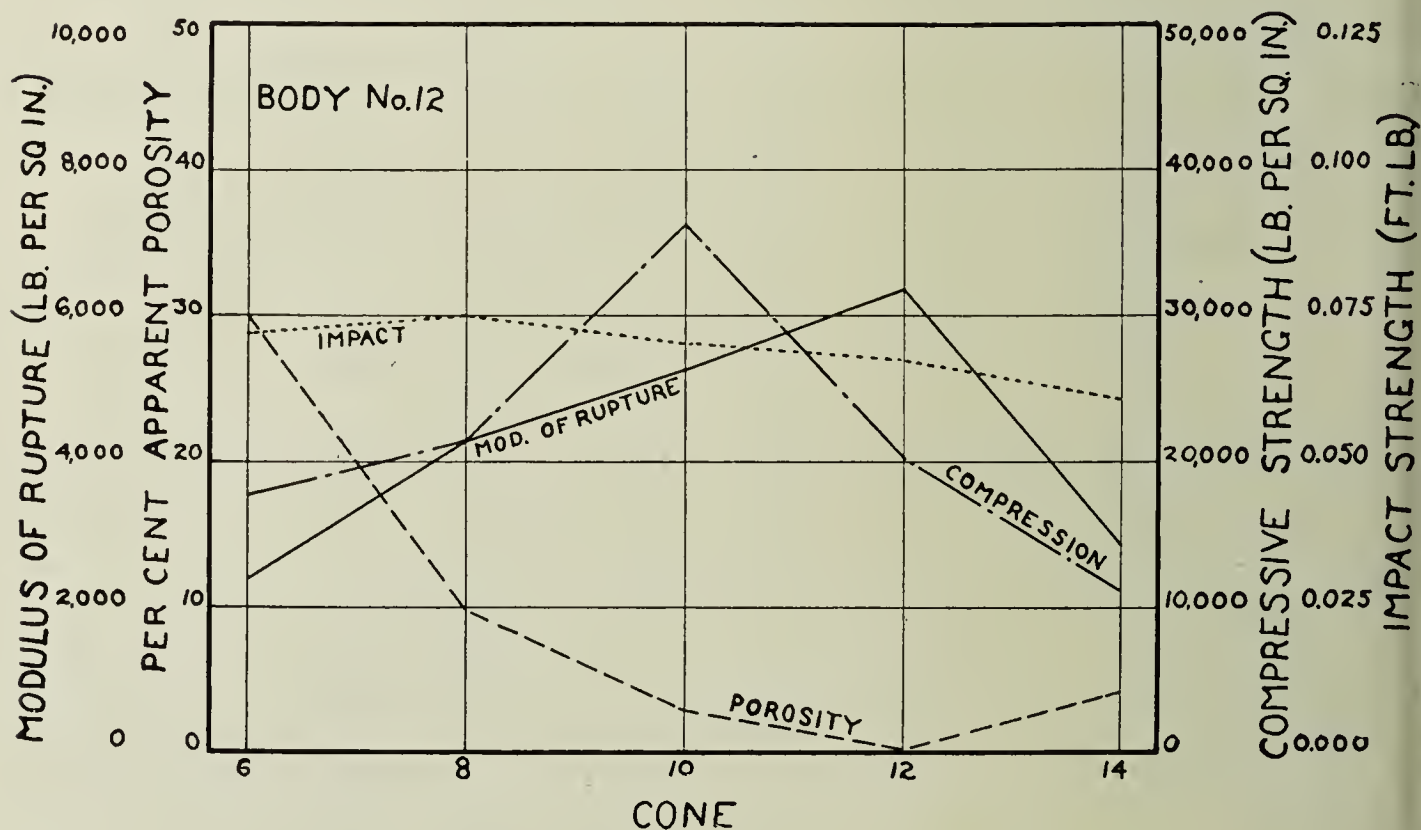


FIG. 29.—Results on body No. 12 fired in the laboratory.

Association for their generous coöperation in the work, P. H. Bates for helpful advice in regard to the testing, and W. L. Shearer, R. B. Fair and John Stanley for assistance in the work in the laboratory.

A NEW RAW MATERIAL FOR CERAMIC USES

By PAUL E. COX AND D. A. MOULTON

ABSTRACT

A mineral, not heretofore reported, similar to feldspar in analysis but partially colloidal like bentonite, is described and some uses suggested for it. Analyses are shown and the properties are described. It should make a very useful material in bodies, glazes and enamels, as it has the properties of a feldspar and the plasticity of a fairly plastic clay.

Introduction

The writers were asked to determine the possible ceramic use of this new mineral from an analysis made by George W. Burke, chemical engineer, in charge of the analytical laboratories of the Engineering Experiment Station of Iowa State College, Ames, Ia.

Physical Tests

Slaking.—A lump of this material was dropped into water for the slaking test. It did not slake like clay but became a jelly-like mass like bentonite. Unlike bentonite only a part of it became jelly-like and it did not swell and fill the vessel. A considerable amount of the material was somewhat like a mixture of kaolin and rather small flat stones, though the stones were so covered with the colloidal portion that they felt at first as though, if time were given, they too would soften. This softening, however, did not occur.

A considerable sample was then placed in a stoneware jar, left to soften, and then lawned through a 100-mesh sieve. It was found that 40% (dry weight) would pass a 100-mesh sieve. The 40% that passed this sieve was colloidal, looking exactly like a well prepared starch paste. To the fingers a little grit was noticeable, but a very little bit of this 40% was other than colloidal.

Plasticity.—The colloidal material alone could be easily thrown on the wheel. Mixed with calcined Florida kaolin and the whole ground to pass a 100-mesh sieve it was found that vase forms could quite easily be thrown from the mixture.

This material would serve as a first rate substitute for feldspar and would be better than feldspar because it would add plasticity. There is no reason to separate the two parts of this mineral unless the benefit of maximum colloidalness is desired for practical reasons.

This ought to be a specially useful material for glazes, enamels and abrasive wheels because it not only functions as does feldspar but it will serve to float the non-plastic grains.

Fusion.—The two parts of this mineral were tested for the fusion points in a carbon resistance furnace.

The colloidal part fused down between cones 7 and 8, while the crystalline

part fused down at about cone 6. The crystalline part had been ground for about twenty hours in a ball mill, all of it readily passing a 100-mesh sieve. When the cone of this crystalline material was taken from the furnace it was found to be dark brown in color, like Albany slip. Repeated tests, with every precaution against contamination gave the same results. Inasmuch as the Orton cones are made from materials that analyze somewhat as this mineral, and in the same tests, they were white as usual, Mr. Burke's analysis was suspected and the material was re-tested.

The colloidal part yielded a light gray fusion. Mr. Burke's analyses are as follows:—

CHEMICAL ANALYSES			
	Analysis of whole sample	Held by 100-mesh	Passed 100-mesh
SiO ₂	67.84	68.46	63.60
Fe ₂ O ₃ }	15.43	0.64	2.15
Al ₂ O ₃ }		13.72	15.82
TiO ₂ }		0.15	0.20
P ₂ O ₅		0.59	0.35
CaO	0.82	1.59	1.13
MgO	1.33	2.05	0.54
Na ₂ O }	5.01	6.77	5.51
K ₂ O }			
H ₂ O	9.57	6.03	10.90
MnO		.01	0.017

It seems hard to believe that in the part held on the 100-mesh sieve there was colorant enough of any sort to yield an almost jet black cone, even with the reduction incident to a fusion in a carbon resistance furnace.¹

Test in Glazes

That part held on the 100-mesh sieve was used in compounding a bright glaze, designed to mature at cone 03, consisting of 40% of this non-colloidal material and 60% of white lead. This glaze was dipped on dry pressed white biscuit tiles, and on a tile made in the plastic way, (a rolled-out bit of clay) from an Iowa shale. The samples were fired in a small electric furnace in about seven hours, yielding perfect glazes, with no crazing on the shale sample and some crazing on the lightly fired white biscuit tiles. A commercial test of this glaze stained with copper oxide on flower bowls gave perfect results in an 18-hour burn.

The resulting glazes show nothing of the black or brown, though on the deeper modeling of the white tiles a warm yellow shows, though not deeper than is commonly seen in glazes rich in lead oxide. This verifies the truth of Mr. Burke's analyses and it would pay the glaze and body makers to investigate this material.

¹ The writers would like to have this point cleared by those experienced in the handling of porcelains under reducing conditions.

Origin

S. L. Galpin, of the Department of Geology of Iowa State College believes that this mineral is a decomposed granite or a decomposed granitic rock. Dr. Galpin referred the writers to *Bulletin 708* of the U. S. Geological Survey in which reference is made to *clays* in the neighborhood of Beatty, Nevada, which place is the location of the mineral under discussion. On page 124 of this *Bulletin* are described in detail deposits of clays that were shipped to California potteries from time to time but the properties described are not at all like those of the sample under discussion. For example the statement is made of one of them that the clay was gritty, would not slake down to any degree in water, and that when ground to pass a 20-mesh sieve there was no plasticity. Of another one, page 125, it is said that a very plastic sticky mass resulted, but that it burned to a very white and *porous* body at *cone 10*. No analyses are shown in the *Bulletin*.

Quantity Available

The question then would be as to the extent of the deposit and the uniformity of output possible. A letter to the owner brought a statement that two mineral claims of about twenty acres each comprise the deposit, and that the mineral occurs in six vertical veins of from 6 to 10 feet in width. Outcroppings show these veins to cut clear through the hill from side to side, and it is estimated that they extend to a depth of 3000 feet. The quantity seems sufficient for a time anyhow.

The owner says that a shaft has been dug both horizontally and downward for some distance and that the quality seems to be uniform. It lies on a railroad.

Conclusion

It appears to the writers that this is an even better material than Cornwall stone, because it is much more plastic. It functions as a feldspar in glass, glaze and body, but with the properties of a clay. It appears that there is enough of it to make it worth while. Further work might show that this is the long desired clear slip glaze that was always the desire of the old time stoneware potter to find and the writers expect to continue work, making use of the colloidal part in glaze and enamel work, as has already been done in a small way in body work. It will make a non-plastic material like flint or feldspar plastic, taking a part of the load off the ball clay and kaolin.

THE PROPERTIES OF SOME CLAY-LIKE MATERIALS OF THE BENTONITE TYPE¹

BY H. G. SCHURECHT AND H. W. DOUDA

ABSTRACT

The evidence obtained in this work would indicate that bentonites are mixtures of two or more materials rather than one. The exact composition of these is not known but they are probably mixtures of colloidal silicates and fine-grained kaolinite in varying proportions.

They are characterized by the following properties: Conchoidal fracture; an index of refraction between 1.48 and 1.54; high water of plasticity and volume drying, shrinkage varying from that of highly plastic clays to 114.61% and 195.9%, respectively; and a high alkali plus alkali earth content, usually above 5%. When added in small amounts to certain clays, some bentonites increase the dry strength to a remarkable extent. In firing they vitrify between 1000°C, soften at cones 1-14 and burn to a buff to brown color and therefore can only be used in small amounts in white ware.

It is possible by adding finely ground quartz and small amounts of bentonite to certain fire clays to produce mixtures approaching the Arkansas and certain other glass pot clays in physical properties and in index of refraction. Adding too much bentonite to clays causes them to crack in drying.

Introduction

Large deposits of clay-like materials are found, principally west of the Mississippi River, known as bentonite, which are characterized by unusual colloidal properties, being much superior to true clays in this respect.

Bentonite was described by Knight² under the name of "taylorite," who, upon finding that this name was already in use changed it to bentonite,³ since it occurred in the Benton formation. Knight also pointed out that it resembled ehrenbergite of Germany. Some of the similar materials are montmorillonite, halloysite and leverrierite. "Wilkenite" and "ardmorite" are trade names used to describe particular bentonites.

It is claimed by Dumble⁴ that materials similar to bentonite in Texas were derived from volcanic products. Read⁵ states that the bentonites of Wyoming were derived from the decomposition of feldspar, labradorite, occurring in the anorthosite of the Laramie mountains.

Most bentonites⁶ of Wyoming occur in the Benton and Niobrara forma-

¹ Published by permission of the Director, U. S. Bureau of Mines. Presented at the meeting of THE AMERICAN CERAMIC SOCIETY, St. Louis, Mo., Feb., 1922.

² W. C. Knight, *Eng. Min. Jour.*, **63**, 600 (1898).

³ *Eng. Min. Jour.*, **66**, 491 (1901).

⁴ W. H. Zimmer, "Hydrated Silicic Acid in Kaolin and its Effect on Pottery," *Trans. Amer. Ceram. Soc.*, **3**, 40 (1901).

⁵ George P. Merrill, "The Non-Metallic Minerals," John Wiley & Sons, N. Y., 243 (1905).

⁶ H. Ries, "Occurrence, Properties, and Uses of Clays," John Wiley & Sons, N. Y., 209 (1908).

tions of the Cretaceous period. Deposits are also reported¹ in the Cretaceous and Tertiary periods in the north west and in the Cretaceous period of the great plains region of Canada. As a rule, bentonites occur in the younger geological formations, which may account for their high colloidal content as compared to clays occurring in the older geological periods from which most of the colloidal matter has been washed through weathering.

Bentonite-like substances occur in Wyoming, California, South Dakota, Montana, Arizona, Utah, Texas, Colorado, Mississippi, and Nevada. Other deposits are reported by Ladoo² in New Mexico and in the Edna-onton formation of the Red Deer River, and in the Nicola Valley, B. C. The prices vary from six dollars to thirty dollars per ton in carload lots.

Its use in ceramics up to the present time is limited. It was found by Zimmer³ that similar clays, when added to ceramic bodies, produced more translucent porcelains than kaolin, although the shrinkage is excessive. Because of the unusual colloidal properties of bentonite, the Bureau of Mines is investigating the possible uses of this material as an ingredient in ceramic bodies.

Experimental Methods

The following properties were determined on a number of bentonites and also on some clays for comparison.

1. Index of refraction.
2. Per cent water lost by drying at 110°C.
3. Softening point, cones.
4. Per cent water of plasticity.
5. Per cent volume drying shrinkage.
6. Drying behavior.
7. Color when fired at 1000°C.
8. Strength when added to ceramic bodies.

The indices of refraction were determined with a petrographic microscope, using the Becke line method.

The water lost on drying the air-dry samples at 110°C was determined by first drying the raw bentonite at room temperatures and then at 110°C. The water lost was expressed in terms of the original weight. The softening points were determined by comparison with Orton cones. The water of plasticity and volume drying shrinkage were expressed in terms of the dry weight and volume of the clays respectively.

¹ E. Orton, Jr., "Experiments on the Drying of Certain Tertiary Clays," *Trans. Amer. Ceram. Soc.*, **13**, 782 (1911); J. Keele, "Drying Defects in Some Cretaceous Clays of the Great Plain Region of Canada," *Trans. Amer. Ceram. Soc.*, **14**, 158-60 (1912).

² R. B. Ladoo, "Bentonite," Bur. of Mines, *Repts. of Investigations*, October, (1921).

³ W. H. Zimmer, *Loc. cit.*, 25-45.

The effects of additions of bentonite to 1:1 flint-kaolin mixtures were also studied, and, in this connection, the strength was determined in the dry state and the color and vitrification after firing were studied.

TABLE I

CHEMICAL ANALYSES OF BENTONITES¹

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8
SiO ₂	60.64	57.98	58.68	59.84	60.18	63.20	54.00	55.22
Al ₂ O ₃	23.26	22.46	25.91	11.84	26.58	12.90	24.48	21.00
Fe ₂ O ₃	3.92	3.80	3.97	3.26	...	2.46	3.00	3.61
TiO ₂	0.12	...	0	...	...	0.11	...	...
CaO	0.59	1.92	1.45	2.90	0.23	0.82	2.08	4.94
MgO	2.19	3.24	1.49	2.32	1.01	2.09	2.75	3.04
K ₂ O	0.37	1.35	0	2.34	1.23	0.26	...	...
Na ₂ O	4.33	...	1.39	2.13	...	0.66	1.74	1.56
SO ₃	...	0.75	0.11	...	...	...	...	0.43
CO ₂	...	...	tr.	...	...	3.50	...	tr.
Cl	...	...	0.10	...	...	0.20	...	0
P ₂ O ₅	...	...	0.06	...	...	...	0.71	...
Ing. loss	...	7.93	...	10.50	...	...	...	...
H ₂ O	2.83	...	6.84	...	10.26	13.80	9.12	10.28
Total	98.25	99.43	100.00	95.13	99.49	100.00	97.88	100.08

¹ R. B. Ladoo, *loc. cit.*

No. 1. Yellow, colloidal; Belle Fourche, South Dakota, Analyst, W. A. Selvig, Bur. Mines.

No. 2. Yellow, colloidal; Medicine Bow, Wyo., Analyst, A. G. Van Eman, Owyhee Chemical Products Co., Chicago, Ill.

No. 3. White, colloidal; near Barstow, California, Analysis from Calif. Master Products Co., Los Angeles, Calif.

No. 4. White, fine grained; Otay, San Diego County, Calif.; analysis from Otay-lite Products Co., Los Angeles, Calif.

No. 5. Type of material from near Rock Creek, Laramie Basin, Wyo., T. T. Read. Cassa Mining Co.

No. 6. From Big Horn Basin, Wyoming, Analyst, R. C. Wells, U. S. Geol. Survey.

No. 7. Supposed bentonite, near Shelbyville, Tenn. Analyst unknown.

No. 8. "Ardmorite," probable variety of bentonite; Ardmore, S. D. Analysis from the Refinite Co., Omaha, Neb.

Results

Color.—The color of raw bentonite varies widely in different deposits. It may assume the white cream, buff, green, yellow, pink, brown and even to black color, being similar to clays in this respect.

Fracture.—The fracture of different varieties varies from earthy to conchoidal. The conchoidal fracture, however, is more characteristic of bentonites than of plastic clays.

Hardness.—The hardness of different varieties is between 1 and 1.5.

TABLE II
PROPERTIES OF SOME CLAY-LIKE MINERALS OF THE BENTONITE TYPE

No.	Source	Index of refraction	Per cent water lost by drying samples dried at room temp. 110°C	Softening point cones	Per cent water of plasticity in terms of dry weight	Per cent volume shrinkage in terms of dry volume	Drying behavior	Color when fired at 100°C
1	Sanders, Ariz.	1.480	16.60	3	71.83	69.08	Cracks badly	Buff
2	Daggett, Cal.	1.495-1.505	14.87	8	69.52	94.21	Cracks badly ¹	Buff
3	Creede, Colo. No. 1	1.505	14.93	12	48.07	59.00	Cracks	Buff
4	Lovelock, Nev.	1.505-1.525	10.82	12	78.10	77.26	Does not crack	Buff
5	Unknown	1.5075	16.62	9	58.63	82.57	Cracks badly ¹	Buff
6	Source unknown	1.515-1.525	9.40	3	....	....	....	Brown
7	Newcastle, Wyo.	1.5175	7.26	9	114.61	161.39	Cracks badly ¹	Buff
8	Wyoming	1.5175-1.5375	9.25	4	99.21	162.73	Cracks badly and warps	Brown
9	Belle Fourche, S. Dak.	1.525-1.535	8.79	12	108.07	195.81	Cracks badly ¹	Buff
10	Creede, Colo., No. 2	1.545	1.83	12	37.30	30.16	Does not crack	Buff
11	Enid, Miss.	1.5475	4.64	14	46.16	73.25	Does not crack	Buff
12	Camden, Ark.	1.5575	2.19	27	37.30	41.94	Does not crack	White
13	Gross Almerode clay, Germany	1.5600	1.34	27	22.07	24.21	Does not crack	White
14	Las Vegas, Nev.	1.560	1.68	30	....	....	....	White
15	Glass pot clay, source unknown	1.5615	3.02	29	36.08	41.94	Does not crack	White
16	Houston, Tex.	1.563	0.27	34	....	....	....	White
17	Enid, Miss.	1.563	3.25	30	29.75	32.13	Does not crack	White
18	New York	1.570	4.55	1	40.97	47.38	Does not crack	Buff

¹ These bentonites become very hard on drying.

TABLE III

THE EFFECT OF BENTONITE ADDITIONS ON THE PROPERTIES OF 1:1 FLINT-KAOLIN MIXTURES

Mixture number	Composition of mixtures			Modulus of rupture, lbs. per sq. in.	Mixtures fired at 1000°C	
	Flint	Kaolin	Bentonite		per cent apparent porosity	Color
1	50	50	0	43.87	39.42	Good white
2	50	50	6	87.01	38.90	Good white
3	50	50	15	158.84	37.72	Fair white
4	50	50	24	222.01	38.13	Cream
5	50	50	32	319.37	37.64	Buff

As a rule, bentonites are harder than ball clays, although there are a number of bentonites which are not quite so hard.

Chemical Properties.—The chemical analyses of a number of bentonites are shown in Table I. They are characterized by a high silica content, 54% to 63.2%, a high alkali plus alkali earth content, 2.46% to 9.69%, and a high iron oxide content, 2.46% to 3.97%. Many clays differ from bentonites in having lower alkali, alkali earth and silica contents, although there are also many clays which have similar chemical analyses.

It was reported by Zimmer¹ and Pence² that clays similar to bentonite contain hydrated silica. Although it is not definitely known, in what form the silica is present in bentonite, the evidence collected in this work would indicate that these substances have properties similar to alkali silicates or alkali-aluminum silicates mixed with clay in varying proportions. Bentonites vary in composition from those containing only 11% Al_2O_3 to those having almost the same composition as kaolinite. Those having a composition approaching kaolinite have properties which also approach those of true clays. It is, therefore, difficult to state which materials should be classed as bentonite and which should be classed as clays since it is possible that bentonites are simply mixtures of certain colloidal silicates and fine grained kaolinite particles in varying proportion although this has not yet been definitely proved. The gelatinous properties of this substance are not destroyed upon drying as would be the case with pure hydrated silica; but they regain this property upon mixing with water, probably due to the presence of alkali silicates.

Some bentonites dried at room temperatures lost 16.60% water upon a second drying at 110°C. Clays treated in a similar manner seldom lose over 5% water, hence in this respect bentonites are different from clays, due to their fine grains and hence higher adsorptive properties.

Drying Behavior.—The per cent water required to render bentonites

¹ W. H. Zimmer, *op. cit.*, 25–45.

² F. K. Pence, "The Determination of Hydrated Silicic Acid in Clay," *Trans. Amer. Ceram. Soc.*, **12**, 43–53 (1901).

plastic varies from that required for highly plastic clays up to 114.61%, (see Table II). The volume drying shrinkage varies from that of highly plastic clays up to 195.81%. As a rule bentonites require much more water to render them plastic and have a higher drying shrinkage than clays.

They crack badly upon drying, forming at first a network of fine cracks, which open up as drying proceeds. It was pointed out by Orton¹ and Keele² that bentonite frequently occurs in streaks ranging from one inch up to several feet in thickness among the clays of the Cretaceous and Tertiary periods, and that the poor drying properties of these clays are attributed to the presence of bentonite. Orton reports a high hygroscopic water content, which is probably due to the presence of bentonites, which have a higher content of this water than true clays.

When mixed with sufficient non-plastic ingredients their drying properties are greatly improved.

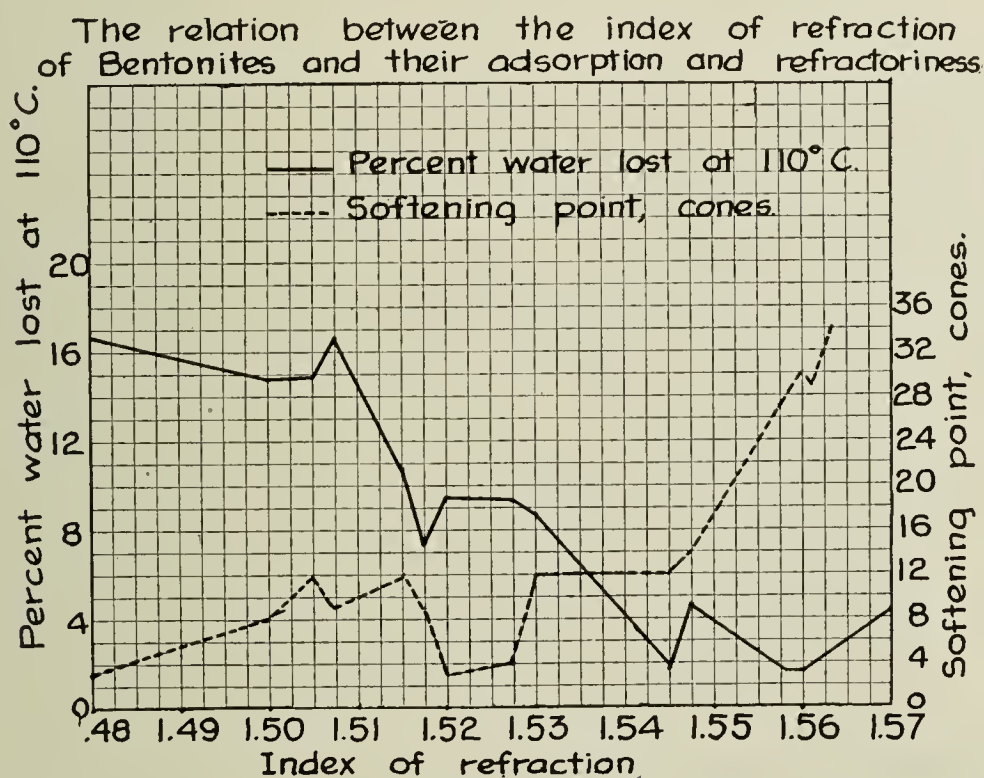
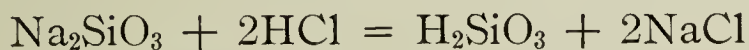


FIG. 1.

When treated with HCl and dried, some bentonites act similar to alkali silicates. For example, when sodium silicate is acidified with HCl and dried at 110°C, it forms H_2SiO_3 and NaCl as is shown below:



The silicic acid after drying becomes set and when remixed with water does not become gelatinous. Likewise if certain bentonites are acidified with hydrochloric acid, dried at 110°C and then remixed with water they lose considerable of their gelatinous properties and after this treatment have a much lower drying shrinkage than the untreated bentonite.

¹ E. Orton, Jr., *op. cit.*, 781-784.

² J. Keele, *op. cit.*, 158.

When suspended in water, bentonites often swell to six times their original bulk volume, as is shown in Fig. 3. The sample on the right shows the volume of a cube of bentonite before soaking in water, and that on the left a similar cube after being suspended in water by means of a wire basket for 12 hours.

Microscopic Properties.—Under the microscope bentonite appears as homogeneous aggregates of extremely fine particles. These particles often cannot be distinguished unless a magnification of 1000 to 1200 X is used.

The following properties of bentonite were obtained by Dr. Leon C. Haven,¹ of the Department of Hygiene, of the Johns Hopkins University, Baltimore, Maryland, using oil immersion lens.

Size of Particles.—Wyoming sample (Owyhee Chemical Products Company), particles range in size from ultra microscopic to $4\text{--}5\mu$. A great majority of grains from $0.1\text{--}0.5\mu$.

California Sample (California Master Products Corp.).—Particles very much smaller on the whole than Wyoming sample. None larger than 1μ . Fully $1/2$ ultramicroscopic or just within range of vision of 1200 X magnification. General run about $0.1\text{--}0.2\mu$. Particles more uniform in size than Wyoming specimens. Not such a range of sizes.

The indices of refraction vary with different varieties from 1.48 up to those approaching kaolinite, 1.563 (see Table II). Those materials having the lowest index of refraction as a rule have the most highly developed colloidal properties. The per cent water adsorbed by the material in general increases and the softening point decreases with a decrease in the index of refraction (see Fig. 1). The index of refraction of hydrated silica varies from 1.40–1.45 and that of certain alkali silicates is only slightly higher. It is possible, therefore, that the lower index of refraction of bentonite is partly due to the presence of similar silicates intimately mixed with fine grained kaolinite, since it was found that by adding sodium silicate to Georgia clay, the index of refraction is lowered in proportion to the amount of silicate added.

Owing to the extreme fineness of grain of bentonite, it was suggested that this lower index of refraction might be due to a high content of adsorbed water. Samples of bentonite and Georgia clay were, therefore, calcined to different temperatures, their indices of refraction determined, and the results were obtained as shown in the table.

It is obvious that even after heating to a red heat, the index of refraction of bentonite does not reach that of kaolinite. A small increase from 1.475 to 1.490 caused by drying the air-dry bentonite at 110°C may be due to driving off the adsorbed water.

¹ Written communication to Raymond B. Ladoo, U. S. Bur. Mines, Washington, D. C.

Refractoriness.—Bentonites vary in softening points from cones 1–14. This low refractoriness, as compared to kaolins, is due to the presence of considerable alkalies, alkali earths, and iron oxide, which act as fluxes, and to the extremely fine grained character of this substance. In

Drying and calcination temp. °C	Index of refraction of Bentonite	Index of Refraction of Georgia kaolin
20	1.475	1.563
110	1.490	1.570
225	1.490	1.570
300	1.498	1.570
325	1.5325	1.570
350	1.5325	1.570
375	1.5325	1.570
400	1.5325	1.570
425	1.5325	1.570
450	1.5425	1.570
500	1.5450	1.570
550	1.5375	1.565
600	1.5375	1.560

this respect many clays differ from bentonites, since they often soften above cone 27, although a number of clays also soften at cones 1–14.

Color When Fired.—The color of bentonites, when fired at 1000°C, varies from buff to brown (see Table II). Since clays often burn to a pure

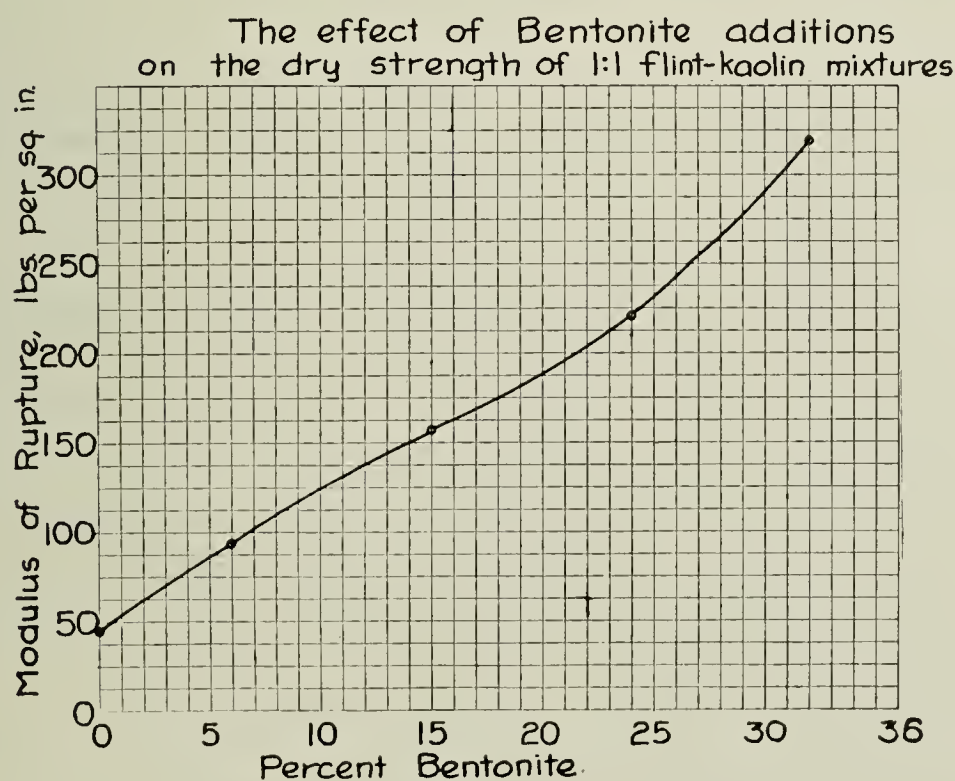


FIG. 2.

white color, they are different from bentonite, which seldom do. A certain amount of bentonite may be added to 1:1 flint-kaolin mixtures without ruining the color (see Table III). The buff color of the bentonite in mixtures containing a low percentage of this material is concealed by

the kaolin since bentonites are fine-grained and become more intimately mixed with the kaolin than if it were coarser grained. Bentonite, if used in whiteware, should, therefore, be added in small amounts only.

Possible Utilization of Bentonite in Ceramics

Comparison of Bentonites with Some Bond Clays.—Sample number 12 (see Table II), is a glass pot clay from Camden, Arkansas. This clay was examined under the microscope and found to contain considerable creptalline quartz. The index of refraction was found to be 1.5575 instead of 1.563, which is the index of refraction of kaolinite. The lower index of this clay may be due to the presence of a bentonite-like substance in small amounts.

Clay No. 11 was reported as being extremely strong in the raw state, but non-refractory. The index of refraction is 1.5475 instead of 1.563, which may also indicate the presence of a bentonite-like substance, hence causing its high dry strength. The alkali and iron oxide which are usually present in high percentages in bentonite would cause its low refractoriness.

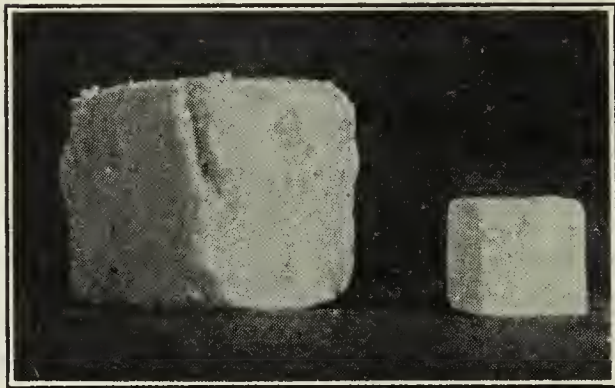


FIG. 3.

Because of its extreme fineness and the ability of some varieties to remain in suspension for long periods of time, it has been suggested that this material

may be used to keep glazes and enamels in suspension. If employed in too great amounts, however, it would cause excessive cracking of the glaze due to its high shrinkage.

The Effect of Bentonite Additions on 1:1 Flint-Kaolin Mixtures

In Figure 2 and Table III are shown the results of bentonite additions to 1:1 flint-kaolin mixtures. The per cent increase in strength is directly proportional to the amount of bentonite added until 25% is employed. $S = KB$ where S is the modulus of rupture in pounds per square inch; B is the per cent bentonite added, and K is a constant for this bentonite. Sample 1 was used in these tests, and whether all bentonites act in this manner remains to be proven.

It may be possible to make synthetic glass-pot clays approaching the Arkansas clays in properties by adding quartz and a small amount of bentonite to certain fire clays. Adding too much bentonite would cause the clay to crack in drying, due to the excessive shrinkage of this substance.

NOTE: The writers wish to acknowledge their indebtedness to R. T. Stull for suggestions and help in the progress of this work.

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ORIGINAL PAPERS

TESTS ON SOME SAGGER CLAYS AND BODIES¹

BY ROBERT TWELLS, JR.

ABSTRACT

Tests on the Sagger Clays.—Bars were made from three typical sagger clays without the addition of grog. After burning at cone 10¹/₂ these bars were tested for *linear shrinkage, transverse strength, dry and fired, absorption of moisture, and dye penetration.*

Tests on Fire Clay-Grog Sagger Bodies.—Two series of bodies were made up into bars. After being burned at cone 10¹/₂ the bars were tested for *linear shrinkage, transverse strength, dry and fired, and resistance to heat changes.* The best body of this type tested was No. 5 which had the composition: No. 8 buff clay, 29.8%; No. 1 fine clay, 18.2%; grog, 6-to 20-mesh, 42.0%; grog, 20-mesh and finer, 10.0%. As a *plant test* 100 saggings were made from this body. At the end of five fires, three were broken, and fifteen were slightly cracked.

Tests on Some Refractory Bodies not Commonly Used for Saggings.—Three bodies were made into bars, fired to cone 10¹/₂ and tested as before. Two proved much superior to those of the fire clay-grog type. Their compositions are:

No.	12	No.	14
Georgia Kaolin	35%	Kentucky Ball Clay	
Tennessee Ball Clay No. 5	10%	No. 4	40%
Grog, 10-40 mesh	55%	Medium Sized Carborundum (fire-sand)	60%
	100%		100%

¹ A report of some of the work done during the autumn of 1920 in the Research Laboratory and Porcelain Department of the General Electric Company at Schenectady, N. Y.

Read before the Whitewares Division, Pittsburgh Meeting, February, 1923.

These bodies, especially No. 14, are of types ordinarily considered too expensive (their first cost) for general use. Are such bodies actually more expensive, when the cost is figured on the basis of the lives of the saggers? They can be determined only by making plant trials of a large number of saggers, determining the relative "cost per fire."

Introduction

At the St. Louis meeting of the AMERICAN CERAMIC SOCIETY, Mr. Treischel¹ submitted a tentative program for coöperative research in the investigation of sagger making problems. Several members differed with him in regard to the method of investigation to be followed. All, however, agreed with him as to the desirability of a complete and thorough study of the whole field. Mr. Bleininger² suggested that the first step should be a survey of the present sagger situation, and a careful review of all previous work. It is to assist in the latter work that this article is submitted.

The primary object of this investigation was to develop a relatively cheap sagger body which would have a longer life in production than the regular mix.

Laboratory Tests of the Sagger Clays Used without the Addition of Grog³

1. Sources of the Clays

No. 8 Buff Clay—a plastic fire clay from Edgar Bros. Co., Metuchen, N. J.

No. 1 Fine Clay—a plastic fire clay from Crossman Co., South Amboy, N. J.

No. 1 White Sandy Clay—a short sandy clay from Ostrander Fire Brick Co., Ostrander, N. J.

These clays were picked for these experiments because they are typical commercial sagger clays, relatively cheap, and available in quantity.

Compositions of Test Pieces

Designation	B	F	BS	BF
No. 8 Buff Clay	100%	.....	62%	62%
No. 1 Fine Clay	.....	100%	....	38%
No. 1 White Sandy Clay	.....	.....	38%	....
	100%	100%	100%	100%

Method of Forming, Drying, and Firing the Test Pieces.—The clays were each ground to pass 20-mesh, weighed, mixed carefully dry; then

¹ C. C. Treischel, "Coöperative Research on Sagger Mixtures and Manufacture," *Bull. Amer. Ceram. Soc.*, **1** [7], 101 (1922).

² A. V. Bleininger, *ibid.*, **1** [7], 105 (1922).

³ Suggested by "The Control of Sagger Mixtures," V. S. Schory, *Jour. Amer. Ceram. Soc.*, **2** [9], 747 (1919).

moistened, and wedged thoroughly. Ten test bars, $1 \times \frac{1}{2} \times 4\frac{1}{2}$ inches, were pressed from each. Shrinkage marks $2\frac{1}{2}$ inches apart were stamped on both sides of each test piece as soon as it was removed from the mold. The test pieces were dried in a Proctor Humidity Dryer in thirty hours. Five test pieces from each body were fired in a Didier-March Tunnel Kiln¹ to a temperature of cone $10\frac{1}{2}$.

Methods of Making Tests.—Linear drying and total shrinkages were determined. Measurements were taken on both sides of each test piece to avoid errors due to warpage. Modulus of rupture tests were made on five unfired and five fired test pieces from each material in a Riehle Testing Machine. A span of $3\frac{1}{2}$ inches between knife edges was used. The pieces were broken with the flat side down. Absorption test was made on three broken fired bars of each, boiling during the 1st, 25th, 50th, 75th, and 100th hours. Dye test was made on the fired pieces soaking in dye solution for 16 hours under a pressure of 250 pounds per square inch.

Results of the Tests

Designation	Av. linear shrinkage per cent of wet length		Av. modulus of rupture lbs. per sq. in.		
	Drying	Burning	Total	Dry	Fired
B.	5.0	9.0	14.0	150	5500
F.	6.0	12.5	10.5	80	4400
BS.	6.0	6.0	12.0	114	2340
BF.	6.0	10.0	16.0	82	7325

Designation	Av. absorption per cent of dry wt.	Dye test
B.	0.14	Non-Porous
F.	5.17	Very non-porous
BS.	—	Very Porous
BF.	1.08	Slightly Porous

Conclusion.—The substitution of the plastic No. 1 Fine Clay, for the short No. 1 Sandy Clay in a mixture containing no grog gives a weaker body in the dry state but a much stronger body in the fired state.

Description of the Grog Used

The grog used consisted of broken saggars crushed in a dry pan and screened to various sizes by a rotary screen. Three sizes of grog were chosen for this experiment because each size was available in large quantities and represented roughly course, medium, and fine mixtures of grog. The screen analysis of each grade of grog was approximately as follows:

¹ L. E. Barringer, "A Continuously Operated Tunnel Kiln for High Grade Clay Ware," *Trans. Amer. Ceram. Soc.*, **18**, 106 (1916).

	Grog No. 1	Grog No. 2	Grog. No. 3
4-6 mesh	55.6%	.....	.....
6-10 mesh	36.4%	82.0%	.....
10-20 mesh	6.2%	14.0%	.....
20M-Finer	1.8%	4.0%	100%
	-----	-----	-----
	100%	100%	100%

Tests of Sagger Bodies

Methods of Making, Drying and Firing the Test Pieces.—The materials entering into each body were carefully weighed out, mixed thoroughly while dry, moistened with water and then wedged. Nine test pieces $1 \times 1 \times 6$ inches were pressed from each body. Marks for linear shrinkage measurements were stamped on opposite sides of each bar immediately after it was removed from the mold. The test pieces were dried for thirty hours in a Proctor Humidity Dryer. Three dry test pieces from each body were retained to be tested for dry modulus of rupture. The remaining six pieces from each body were fired in a Didier-March Tunnel Kiln to a temperature of cone $10\frac{1}{2}$.

Method of Making Tests.—Three dry unfired pieces of each body were broken to determine its unfired transverse strength. They were broken on a home-made machine by loading the center of each bar over a $4\frac{1}{2}$ -inch span. The modulus of rupture was calculated from the usual formula.

The transverse strength in the fired state was determined on three of the fired pieces from each body using a span of five inches.

The three remaining fired pieces of each body were used to determine resistance to heat changes. The test pieces were first placed in the preheating chamber of an electric enameling furnace for five minutes at 450°F ; then pushed into the hot chamber for seven minutes at 1556°F ; then taken out and immediately quenched in water at room temperature. The

Series I

Composition of Bodies

Body Number	1	2	3	4	5	6	7	8
No. 8 Buff Clay	36%	36%	36%	29.8%	29.8%	29.8%	29.8%	27.0%
No. 1 Sandy Clay	22	..	..	....	....	....	....	....
No. 1 Fine Clay	..	22	22	18.2	18.2	18.2	18.2	27.0
No. 1 grog	42	42	..	42	..	..	..	36.0
No. 2 grog	..	..	42	..	42	42	42	..
No. 3 grog	..	..	..	10	10	5	5	10
White Talc ¹	..	..	..	..	..	5	..	..
Asbestos ¹	..	..	..	..	..	..	5	..
	-----	-----	-----	-----	-----	-----	-----	-----
	100%	100%	100%	100%	100%	100%	100%	100%

¹ Magnesia Talc Co., Waterbury, Vermont.

number recorded is the times the piece stood this treatment before it became so weak that it could easily be broken between the hands. The results, with a few exceptions, were remarkably uniform considering the nature of the tests.

The use of talc and asbestos has been suggested by others.¹

Results of Tests

Body no.	Av. linear shrink. per cent of wet length			Modulus of rupture lbs. per sq. in.		Resistance to heat changes, no. of heats withstood.		
	Drying	Burning	Total	Dry	Fired	Min.	Max.	Aver.
1	3.0	1.5	4.5	39.0	520	..	..	11.3
2	5.0	3.7	8.7	18.0	745	..	..	9.5
3	4.0	4.0	8.0	20.0	785	..	..	10.3
4	4.5	3.5	8.0	40.6	860	12	13	12.5
5	4.0	3.0	7.0	43.9	960	13	17	15.0
6	5.0	4.0	9.0	64.0	1360	3	Over 18	Over 10.0 ¹
7	5.0	4.5	9.5	84.5	1280	13	Over 18	Over 15.0
8	5.5	3.5	9.0	41.1	1230	7	8	7.6

¹ One bar broke at three heats, one at ten heats, and one did not break in eighteen heats.

Comment on Results.—1. A comparison of Bodies No. 1 and No. 2 shows that the substitution of the plastic No. 1 Fine Clay for the No. 1 White Sandy Clay increases the shrinkage, decreases the dry transverse strength and increases the fired transverse strength. This agrees with the results on the same mixtures of clay but without grog. Body No. 1 containing the sandy clay shows better resistance to heat shocks.

2. A comparison of Bodies No. 2 and No. 3, also Bodies No. 4 and No. 5 shows that the substitution of the medium grog (No. 2) for the coarse grog (No. 1) increases the dry transverse strength, the fired transverse strength, and the resistance to heat changes.

A comparison of Bodies No. 2 and No. 4, also No. 3 and No. 5 shows that replacement of 10% of clay by 10% of fine grog (No. 3) doubles the dry transverse strength, increases the fired transverse strength and increases the resistance to heat changes.

3. A comparison of Body No. 6 with Body No. 5 shows that replacement of 5% of fine grog (No. 3) with 5% of talc increases the shrinkage, and increases the dry and fired transverse strength approximately 50%. With the exception of one very low result the test pieces containing 5% of talc also show high resistance to heat changes.

A comparison of Body No. 7 with Body No. 5 shows that the replacement of 5% of fine grog (No. 3) with 5% of asbestos increases shrinkage, increases dry transverse strength 50%, increases fired transverse strength about 33 $\frac{1}{3}$ %, and slightly increases resistance to heat changes.

¹ George Simcoe, "Importance of the Sagger Making Department," *Trans. Amer. Ceram. Soc.*, **17**, 256 (1915); "Saggers! Past, Present, Future, their Scientific, Humanitarian and Commercial Aspects," *Trans. Eng. Ceram. Soc.*, **14**, 27 (1914-15).

4. A comparison of Bodies No. 4 and No. 8 shows that a 6% increase in total percentage of clay at expense of coarse grog (No. 1) combined with an 8.8% increase of No. 1. Fine clay has the effect of increasing fired transverse strength about 50% but reduces resistance to heat changes over 33¹/₃%.

Conclusions.—Of the bodies tested in Series I Bodies 1, 4, 5, 6, and 7 seem to warrant further laboratory tests and trials under plant conditions.

No. 6 and No. 7 bodies look promising. The chief question would be whether or not they would hold up the required load at a given temperature without sagging.

Series II¹

Compositions of Bodies

Body Number	1	9	10	5	11
No. 8 Buff Clay.....	36%	36%	36%	29.8%	28%
No. 1 Fine Clay.....	..	11%	..	18.2%	28%
No. 1 White Sandy Clay.....	22%	11%	..	...	..
Raw Flint Fire Clay..... (Harbison-Walker)	..	..	22%	...	..
No. 1 grog (Coarse).....	42%	42%	42%	...	36%
No. 2 grog (Medium).....	..	..	..	42.0	..
No. 3 grog (Fine).....	..	..	..	10.0	8
	100%	100%	100%	100%	100%

Results of Tests

Body no.	Av. linear shrink. per cent of wet length			Av. modulus of rupture lb. per sq. in.		Resistance to heat changes no. of heats withstood		
	Drying	Firing	Total	Dry	Fired	Min.	Max.	Av.
1	3.6	2.9	6.5	34	830	14	18	16.0
9	4.1	4.1	8.2	29	1050	4	14	10.0
10	2.7	7.0	9.7	32	810	5	14	10.7
5	4.4	3.5	7.9	35	1120	12	19	15.7
11	5.3	2.4	7.7	41	1110	13	17	15.0

Comment on Results.—1. The results of the tests on the fired pieces run somewhat higher than one would expect from the results of Series I. This is particularly true of Body No. 1. It may be partially accounted for by the fact that the sandy clay used in this series came from a later car and seemed to be of a somewhat more clayey nature than that used in the first series.

2. A comparison of the results of tests on Bodies No. 1 and No. 9 tends to confirm the conclusion that the substitution of No. 1 Fine Clay

¹ This series consisted of two of the best bodies from Series I and several other bodies of a similar nature. The forming, drying, firing and testing were performed exactly similarly to that for Series I.

for No. 1 White Sandy Clay increases the shrinkage, decreases the dry transverse strength, increases the fired transverse strength and decreases resistance heat changes.

3 A comparison of Bodies No. 1 and No. 10 shows that the substitution of raw flint fire clay for the No. 1 White Sandy Clay increases the firing shrinkage and reduces the resistance to heat changes. The dry and fired transverse strengths are practically the same in each case.

Conclusions.—From the results of these laboratory tests the bodies rank as follows: No. 5, first; No. 11, a close second; and No. 1, third.

Series III¹

Sources of Materials:

- Georgia Kaolin-Edgar Bros. Co., McIntyre, Ga.
- Tenn. Ball Clay No. 5-Mandle Clay Mining Co., St. Louis, Mo.
- Kentucky Ball Clay No. 4-Ky. Construction and Improvement Co., Mayfield, Ky.
- Flint Fire Clay-Harbison-Walker Refractories Co., Pittsburgh, Pa.
- Carborundum Firesand, Carborundum Co., Niagara Falls, N. Y.

Composition of Bodies²

Body number	12	13	14
Georgia Kaolin.....	35%	..	..
Tennessee Ball Clay No. 5.....	10%	..	..
Kentucky Ball Clay No. 4.....	..	56%	40%
Raw Flint Fire Clay.....	..	24%	..
Medium Sized Carborundum			
Firesand.....	..	..	60%
Grog ³			
10-40-mesh.....	55%	..	..
10-26-mesh.....	..	15%	..
20-mesh to Dust.....	..	5%	..
	100%	100%	100%

Results of Tests

Body no.	Av. shrinkage per cent of wet length			Av. modulus of rupture lbs. per sq. in.		Resistance to heat changes no. of heats withstood		
	Drying	Firing	Total	Dry	Fired	Min.	Max.	Av.
12	3.7	2.0	5.7	23	680	All over 25		..
13	5.0	7.7	12.7	120	1830	9	15	12.7
14	4.6	0.6	5.2	110	1730	All over 25		..

¹ This series consists of refractory bodies somewhat different from those usually used. These bodies were made, fired and tested at the same time as those of Series II, but they are reported separately owing to their different nature.

² Body No. 12 was suggested by F. H. Riddle, "Porcelain for Pyrometric Purposes," —"Pyrometry," p. 240 (1920), *Am. Inst. of Min. Met. Eng.*; Bodies No. 13 and No. 14 were suggested by two crucible bodies by H. Huisken, Thesis, June, 1920, U. of Ill.

³ Calcined flint fire-clay grog was recommended in the original formulae. In this series, ordinary sagger grog was used because it could be gotten cheaply and plentifully

Comment on Results.—The results of the tests on Bodies No. 12 and No. 14 indicate that they are much superior to any body previously tested. Their chief drawback for plant use is the high cost of their materials. No. 12 seems to be very promising as a basis for future work on sagger bodies containing high grade clays. Modifications of it and No. 14 might prove successful enough to warrant the additional cost.

Plant Trials

From the results of the laboratory tests, No. 5 was picked as being the best of the fire clay-grog bodies. Under the direction of Mr. L. E. MacFadyen, 100 saggors were made from this body for trial under plant conditions. These saggors were formed in a hydraulic press after the body had been tempered in a wet pan and pugged through a horizontal mill.

Four slightly different methods were used in the making of the unfired saggors: 50 saggors were made using dry grog: 50 saggors were made using water-soaked grog: half of each set of 50 was dried rapidly in a steam drier, while the other half was dried more slowly in the open air on top of the steam drier. These different treatments did not seem to be a material factor in the results. All of the saggors were flawless after drying. For their first fire the green saggors were placed in a round periodic kiln in five bungs, each bung twenty saggors high. After the first fire the saggors were fired carrying the regular load of ware. Records were kept only as far as the fifth fire.

Results: ¹ (about cone 10 ¹ / ₂)					
No. of fires.....	1	2	3	4	5
No. of broken saggors.....	1	2	2	3	3
No. of slightly cracked.....	4	13	14	14	15
No. of missing saggors.....	0	10	9	15	19
No. flawless saggors.....	95	75	75	68	63
	—	—	—	—	—
	100	100	100	100	100

General Conclusions

Body No. 5 proved to be better than the regular sagger mix both in plant and laboratory tests. This accomplished the primary object of these experiments by the development of a good sagger body from relatively cheap fire clay-grog materials.

¹ Abstracted from Mr. MacFadyen's report. This makes a very good showing for this type of sagger. The saggors which were listed as being slightly cracked were still strong enough to be used for ware. The saggors listed as missing were misplaced by workmen. Most of these missing saggors turned up later. In practically every case they were in good condition when found. Accurate plant service records of any of the other bodies cannot be given. Body No. 1 stood up rather poorly in use. An estimate was made that it averaged 5 times through the kiln before breaking. A few saggors made from a body similar to No. 14 were still good after 20 trips through the tunnel kiln.

Incidentally Bodies No. 12 and No. 14 made from somewhat more expensive materials were superior in the laboratory tests to any of the cheaper bodies. These laboratory results were partially confirmed by plant tests.

The chief objection to sagger bodies of types similar to No. 12 or No. 14 would be their high initial cost. This very common basis of comparing the costs of sagger mixes is obviously wrong. The relative cost of a sagger body should be based on the average cost per fire, which would also take into consideration the lives of the sagers. Positive data for such a comparison can be obtained only through actual plant trials of a large number of sagers from each mix, keeping accurate records of their first cost and firing behavior. On this basis of comparison sagers made from expensive materials might in the end prove less costly than those made from cheaper materials.

HIGHLAND PARK, MICH.

EXPERIENCES WITH DUTCH KILNS

BY ROY A. HORNING

Description

The Dutch kiln is about the simplest form of kiln. For the benefit of those not familiar with this kiln a brief description may be worth while.

Essentially a Dutch kiln has only four permanent walls, no crown, and it may or may not have fire boxes. Usually a Dutch kiln will have grates extending all the way through the kiln or they may extend into the kiln only a short distance. The newer kilns have grates running all the way through and have large ash pits. On each side of the kiln are firing holes, the number of which depends entirely upon how many arches are to be set. Roughly there is one arch to each 20,000 bricks. The capacity of the kiln depends on how many arches it can accommodate. They may run as low as five arches or they may run as high as twenty-four arches. Usually a roof (either fire proof, or removable wooden) is placed well above the kiln, merely as a protection against the weather.

Some plants deem it wise to enclose the kilns completely within a building. This is not necessary and only under very extraordinary conditions is this desirable. The kilns, under the supervision of the writer, have an improvement that means a great deal to the burner. Thirty inches from the top of the walls a three foot walk is placed and attached to the kiln by steel brackets. This walk enables the burner to get around the top of the kiln with ease and safety and it also gives him a chance to put coal along the head walls during the burn. This feature will be described a little later.

Setting

There are as many different ways of setting brick in Dutch kilns as there are owners of them. Each man has some little thing that he does differently from the others. Essentially they are set the same. First of all there are the arches. These may be set high or low, depending on the nature of the clay and the width of the space between the arches. We close up with four overhangers with eight courses below them. It is possible to set brick fifty or fifty-five high depending on the nature of the clay and also somewhat on the coal.

After the kiln has been filled it is covered with a flat course of brick known as platten.

Burning

Preparation for Burning.—After the kiln has been filled the entire top of the kiln is covered with a layer of buckwheat coal; about forty pounds

to the thousand. This is scraped into the top course with no attempt to work it down into the setting. The platten is then placed on this, leaving every other pair standing on end. The casings are run up and given a good thick coat of daubing. The arches are filled with fire wood and about six tons of egg or broken coal are equally distributed through the arches.

This wood and egg coal gives a good dry heat for about twelve hours. This enables the steam to start from the brick and gets the draft started without the danger of sooting up the setting. This fire is followed with low volatile bituminous firing with the ash and fire doors wide open to give the kiln plenty of air. The heat is kept moving as fast as possible, watching carefully that the arches do not get too hot. After about twenty-four hours the kiln doors are partially shut and from then on the movement of the fire governs how wide each door is to be kept open. It is by this means that the fire is driven from one place to another in the kiln. At the end of forty-eight hours we aim to have the fire through the top of the kiln. As fast as the fire works out we put the platten down. When the fire is up uniformly over the kiln we start to settle, and when the middle has settled about two inches we coal the heads.

In coaling the heads the burner goes up on this platform and by means of a special shovel he lifts the platten three at a time two courses in from the head. The helper then throws a bucket of buckwheat coal into this opening and works it down with a rod. The kiln is then ready to settle. The settling is done in the next twenty-four hours and is carried on uniformly until there is thirteen and one half inches. In kilns having twelve arches and holding about 250,000 brick the whole burning process is carried out in seventy-two hours.

This length of time will perhaps sound a bit small but it is done with surprising regularity and sometimes we finish one in less than this time. The chief advantage of the coal put in on top is that when the fire is about half way up there is enough heat to ignite a part of the coal that has worked itself down into the setting. As soon as this coal is ignited the fire immediately runs through to the top. This saves the time which would be required if the heat was generated only in the arches. We aim to put in sufficient coal to burn the top courses. This also saves time as it would otherwise require much longer to force all the heat from the bottom to the top. Another feature is a higher percentage of hards. We often have kilns that run a uniform color to the top course, all being hard.

We have burned brick at this plant for three years and have four distinct kinds of clay that we burn from time to time yet all of them can be handled in about the same length of time. Of course, there are some variations in the way the different clays are fired.

Statistics on Burns

In three years operation

Average time of burn 71 hours,

Average percentage of hards 90.5%

Average kiln loss Culls .5%

Average coal consumption 315 lbs. per M

This coal consumption includes all coal: egg, buckwheat and bituminous.

There are some objections to this method of burning in that you get a distribution of ashes among the burned product, this is objectionable only to the men and then only in a strong wind. We have never had a complaint from a customer about it.

LANCASTER, PA.

CONSTRUCTION FEATURES OF IMPORTANCE TO CLAY PLANTS

BY T. W. GARVE¹

ABSTRACT

The paper discusses and illustrates constructional problems in clay working factories namely: Construction work during winter; Laying-out; Earthwork; Road and Railroad; Formwork, Concrete, and Machinery setting; Kilns and Stacks.

Considerations prior to the work, etc., are found under heading: General Recommendations.

Introduction

A brick plant is seldom complete in the first instance. It is at all times subject to developments. There is, as a rule, no definite unit. The builders start with a definite proposal as to capacity but the several processes do not work out as expected: they are not in balance. The balancing work begins and seems never to end. Whatever the explanation, construction work is an annual feature in most clay working plants, and it is the purpose of this paper to discuss such constructional problems.

General Recommendations

The first step in any improvement should be plans and specifications. Too many clayworkers plan improvements by looking over the situation, and proceeding without further consideration, only to find later that they have made a number of blunders which would not have occurred if the project had been worked out on paper and fully considered before starting the work. The blunders may temporarily be overcome, but hardly corrected, by some makeshift which will be a continual source of annoyance and expense.

A careful estimate of the cost of the improvements should be made and covered by an appropriation.

Each clayworker should have a plan of his plant, in tracing, from which blue prints can be taken and used for study and submission to engineers, machinery concerns, and others for advice in every proposed improvement. These should show not only property and buildings to scale but also all machinery with shafting and drives and all the equipment together with notes on sizes and make. Also building posts or columns should be indicated and all wiring, piping, and drainage. The size of all piping and drains should be marked and also all valves and intakes. Such a drawing should be kept up to date. Such a print is the best record available for checking up the equipment, for locating leaks or stops, and for getting necessary and accurate distances and clearances.

It is advisable to do construction work, if at all possible, during times of depression. It will insure lower material and labor costs, and will receive closer attention and more prompt shipments of materials, and will cause less interference with regular production.

¹ Recd. May 15, 1923.

For a new plant or large extension, it would be advisable to have a construction engineer who will work in harmony with the management and the construction foremen but who will have vision and nerve enough to go ahead on his own responsibility. The construction engineer should be careful yet firm and quick in his decisions and actions. He must be an inspiration to the men. He should demand work for pay without being a driver.

On large jobs, it is desirable to use time slips of a special color and especially designed. They should be handed to the construction engineer every night who then can make his entries before delivering them to the time keeper. Different sections of the work such as different buildings or different classes of work like excavating, concreting, carpentry, brick-laying, etc., should have special numbers marked on the time slips. This will enable the engineer to see whether each job is progressing within the estimated cost. It is important that the engineer in charge should be feeling the pulse of the work at all times, and for this the time slips are excellent.

The tool, office and lunch shanties for the construction gang can be portable or collapsible buildings, the roof, floor, and four sides of which are complete and separate units, bolted together or simply hooked together. It will permit of easier transportation of the buildings around the works saving time and labor, and the salvage will be greater at the end of the job.

The tractor is a most helpful and useful contrivance for almost any kind of construction work. We have successfully done rooting, plowing and scooping with a tractor and two Maney scrapers; have driven the saw mill, the cross cut saw, the machinery of the plant; have hoisted building timber, steel, and other material; tilted up concrete chuting tower; pulled up complete roof trusses; unloaded and moved heavy machinery and equipment; moved railroad cars, shanties, logs, etc.

Another modern contrivance is a Ford truck with a flat bottom that can be tilted by its own power. It can be used for excavating or filling purposes, for hauling and placing sand, gravel, stone, coal, or else it can also be used for hauling the men to and from work. Of course, it will not entirely replace teams.

There should be a winch, two sets of blocks with tackles and snatch blocks, and pipe or wooden rollers. Good hemp rope in various lengths should be kept indoors whenever not in use.

Be sure that shipments are made in proper time to keep the work going at its maximum. This applies to machinery as well as to building materials.

It is important, in order to avoid second handling and confusion, to place every shipment in its proper place to prevent again being moved.

A railroad car will hold as an average about 200 barrels cement, equal to 800 bags, 16,000 board measure of heavy timber and 20,000 board measure of light timber, 16 cords of wood, 45 cubic yards of sand plus gravel, etc.

Construction work should be protected against fire and accidents. Such safe-guards have to be changed continually.

Construction Work during Winter

Most construction work on heavy clay product plants in the northern and middle states is done during the winter when orders are not rushing. There are many points in its favor especially if the season happens to be an open one. It is important that all brick and concrete work be protected from frost until the mortar and concrete are so dry and hardened that no water is left to freeze.

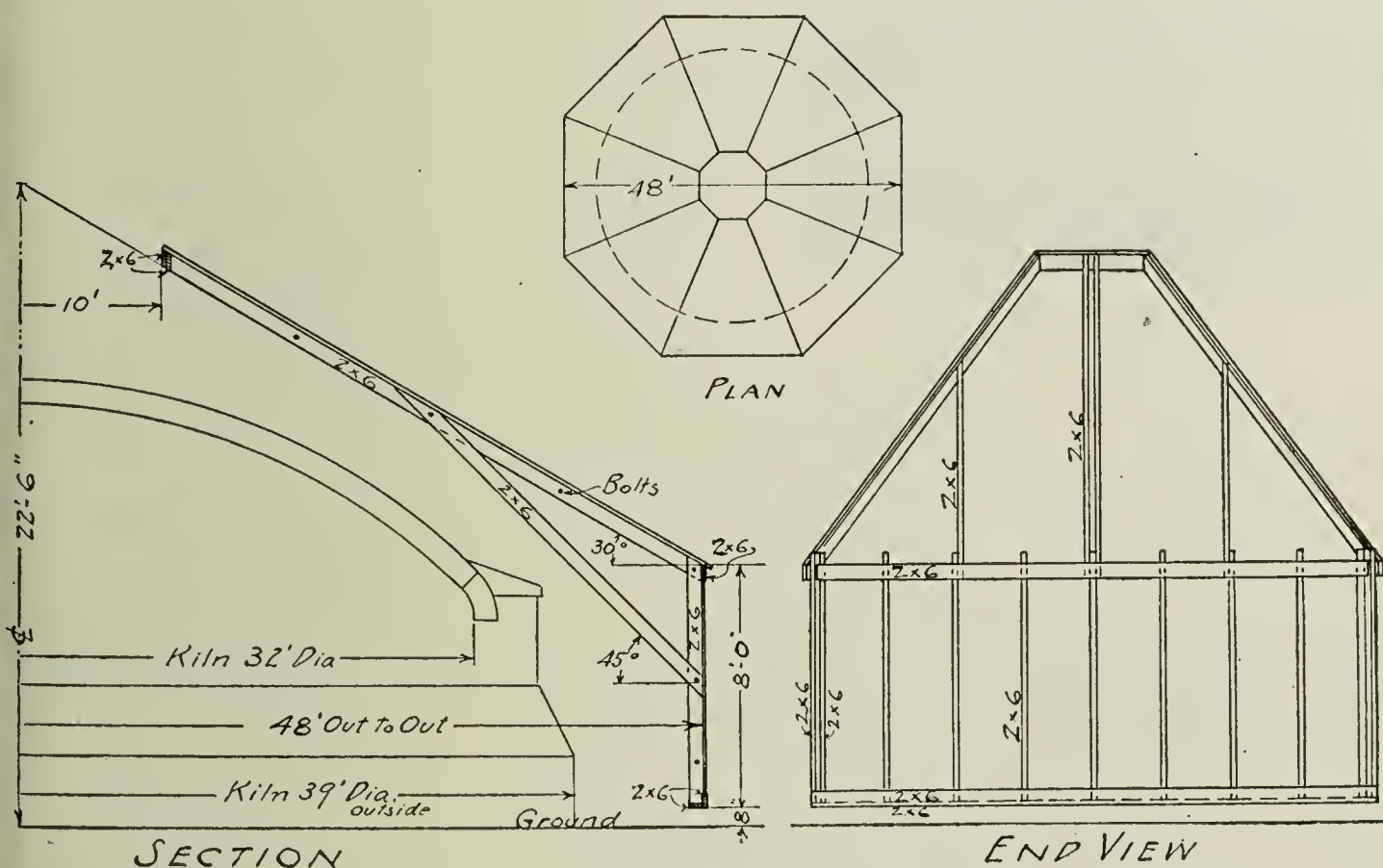


FIG. 1.

To effectively accomplish this often requires a lot of time, labor, and extra expense. Use of hot water and heating of the sand will help some but they will cool rapidly after being placed; salamanders and coal stoves may be set up so the wind will drive the heat and smoke towards the work. The direction of the wind might change suddenly over night and the cold continue long enough to do a lot of damage if proper care has not been taken.

Empty cement bags, boards, roofing-paper, straw and manure can be laid over the concrete. A concreted trench can be protected by covering the top, and then placing oil lamps inside of it. It is advisable to purchase several large tarpaulins before commencing winter work. They can also be used to great advantage for protection of men, machinery and equipment against rain (See Fig. 8).

Winters with continually changing temperatures from below to above freezing are apt to do more damage than cold steady winters.

Brick or concrete stacks should not be built during winter. It is advisable to have all the outside walls and crown of kilns done before the cold weather sets in, and then build the kiln bottoms and bag walls during winter with salamanders for protection. If no coke can be had for salamanders, it is better to use coal stoves.

When constructing a number of round kilns during winter, we have found it advisable and profitable to erect a construction shed, as seen in



FIG. 2.

Figs. 1 and 2. It is octagon in shape and the sections are bolted together. The cost is about \$600.00. A number of uses can subsequently be found for storage, garage, etc.

All brick used for construction during winter should be stored under roof.

Avoid use of frozen sand or gravel for leveling or tamping under railroad ties or for other use. It will yield after thawing and throw the work out of line or level. Keep frost balls out of the mixer.

All the pipe lines should either be properly protected (underground in sawdust) or be drained every night. All valves should have drip cocks. One man should be responsible for the pipe lines, attending to them every night and inspecting them the first thing every morning. All the piping, which is apt to freeze, should be painted red.

Laying-Out

We consider it essential that the construction engineer shall be familiar with the operating of the plant under construction whether it be the plant kiln or drier. A drawing might not be fully clear or dimensions not checked or errors not detected that will require quick decision and remedy. We have seen the most artistic picture drawings which were practically worthless to the construction engineer. He had to develop speedily his own sketches.

There should be a transit, and also a small level. There are special builder's levels which have a tilting telescope. They are light and easily handled but not as sensitive nor as accurate as transits. We prefer a transit for plant layout.

No stakes should be placed at corners of buildings nor at centers of posts for in excavating they will have to be removed. Corner stakes, set a few feet outside (Fig. 3) can remain undisturbed and the work checked at any time. It is essential to establish a grade line high enough so that

the bottom of the deepest pit will be above the high water mark of the underground water.

Earth Work

Steam shoveling is the only and proper method for deep cuts of over four feet and for hard material. It costs between 30 and 50 cents per cubic yard. Contract should be let on cubic yard basis.

For soft ground, like loam, top soil, gravel, or sand, less than four feet in depth, and not to be hauled distances exceeding one hundred feet, scoops and teams will give the best results, costing around 50 cents per cubic yard.

Scoop work can often advantageously be done in connection with steam shovel work for trimming off the edges or for some special excavation of minor depth. Scoops can also be used on large machinery foundations.

The capacity of a scoop, dragged by two horses, is one quarter cubic yard. Most often the ground requires some plowing before scoops can be used. This can be done by teams but often most advantageously by tractor.

For small machinery foundations and trenches for building walls, the pick and shovel method is the only one, though it may figure per cubic yard three times as much as the scoop method, costing anywhere from \$1.00 to \$2.00 per cubic yard.

The large Maney scrapers of a rated capacity of one cubic yard can be used to advantage with a tractor. We have used one and even two on one tractor.

Whenever possible, any kind of earth work should fulfill the double purpose of a necessary cut in one place and an essential fill in another place.

Road and Railroad

Burned waste material, also ashes with cinders are available and they should be used unsparingly for road building and upkeeping.

The vehicle road connection should be given as much study as the railroad switch.

Steep roads, even for short distances, should be avoided, keeping below 3 per cent grade.

For railroad switch, figure about one and a half foot from top of rail to the ground, whether cut or fill, for the rail, the tie, and the ballast. After the ground is fairly level, place the ties on the ground about two feet apart, actually 16 ties for each 33 feet rail length. Then roll the rails on top of the ties, breaking joints, and bolt with fish plates each line of rail. Then locate one rail line in reference to the ties by measuring with a 21-inch stick from outside web of rail to end of each tie, and then drive the spikes, two in each tie diagonally opposite each other.

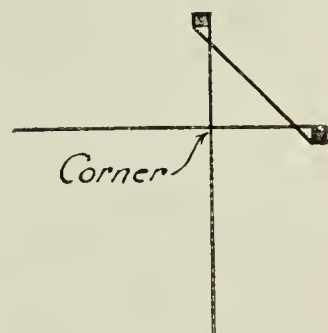


FIG. 3.

The other line of rail is spiked after using the gage from the first line. Special tie plates should be used at switches and also at curves between top of tie and bottom of rail. Dump the ballast (cinders or gravel) over the track, and raise the track by railroad jacks to level marked by stakes

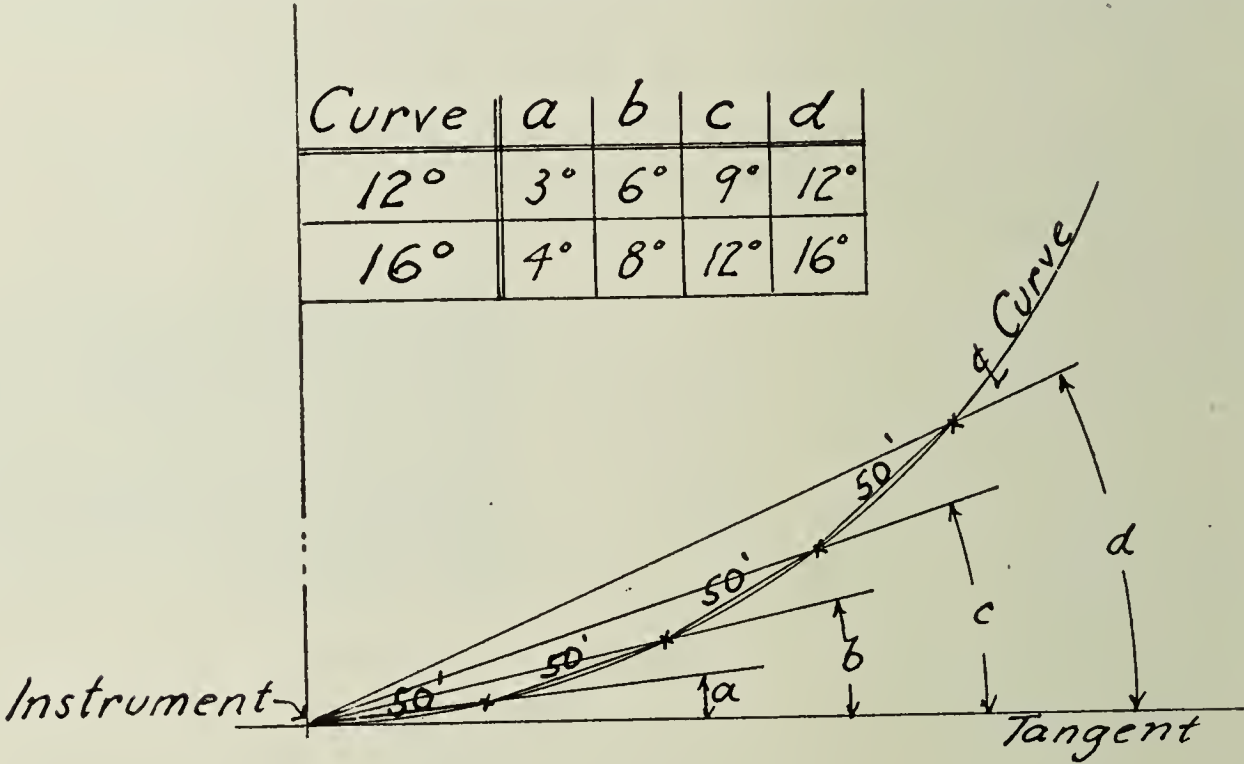


FIG. 4.

and work the ballast underneath tightly with tamping picks for about two feet under the rail but not all along the tie. This should be done roughly all along the line. Later go over again in the same way for finer adjustments which can be well judged by the eye.

For curves, no rail benders are required. The line is simply bent or forced over with crow bars after the rails have been bolted together firmly.

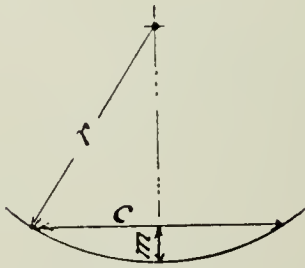


FIG. 5.

Degree of curve	Radius of center line of curve	Radius inner rail inside r	For cord c = 50' Middle ordinate m =	For cord c = 62'-4" Middle ordinate m =
12°	478.34	447.59	8"	12"
14°	410.28	379.53	10"	14"
16°	359.26	328.51	12"	16"

The curve can be laid out with a transit using iron pins every fifty feet in the center of the track, as shown in Fig. 4. The railroad companies usually do not permit of a curve more than 12 degrees but 16-degree curves are built for light equipment.

No railroad grade should exceed 1½ per cent.

Ninety pound rails should be used and not lighter than eighty pound rails for factory switches. The outer rail of a curve should be between

2 and 4 inches higher than the inner rail to prevent the flange from crawling up the outer rail.

A simple way of ascertaining the degree of a curve is by holding a tape against the inner rail and measuring the middle ordinate. We have figured it out for a 50-foot cord, though the customary method is to use a cord or tape length of 62 ft. 4 in. where the middle ordinate is numerically equal to the degree of the curve (see Fig. 5).

In calculating a railroad bank or fill, it should be borne in mind that the angle of repose is to be taken as $1\frac{1}{2}$ to 1, which will make the bottom of a high bank or the top of a deep cut extremely wide. The top of a railroad bank should not be less than 12 ft. and better not less than 14 ft. wide, the ties being 8 ft. 6 in. long.

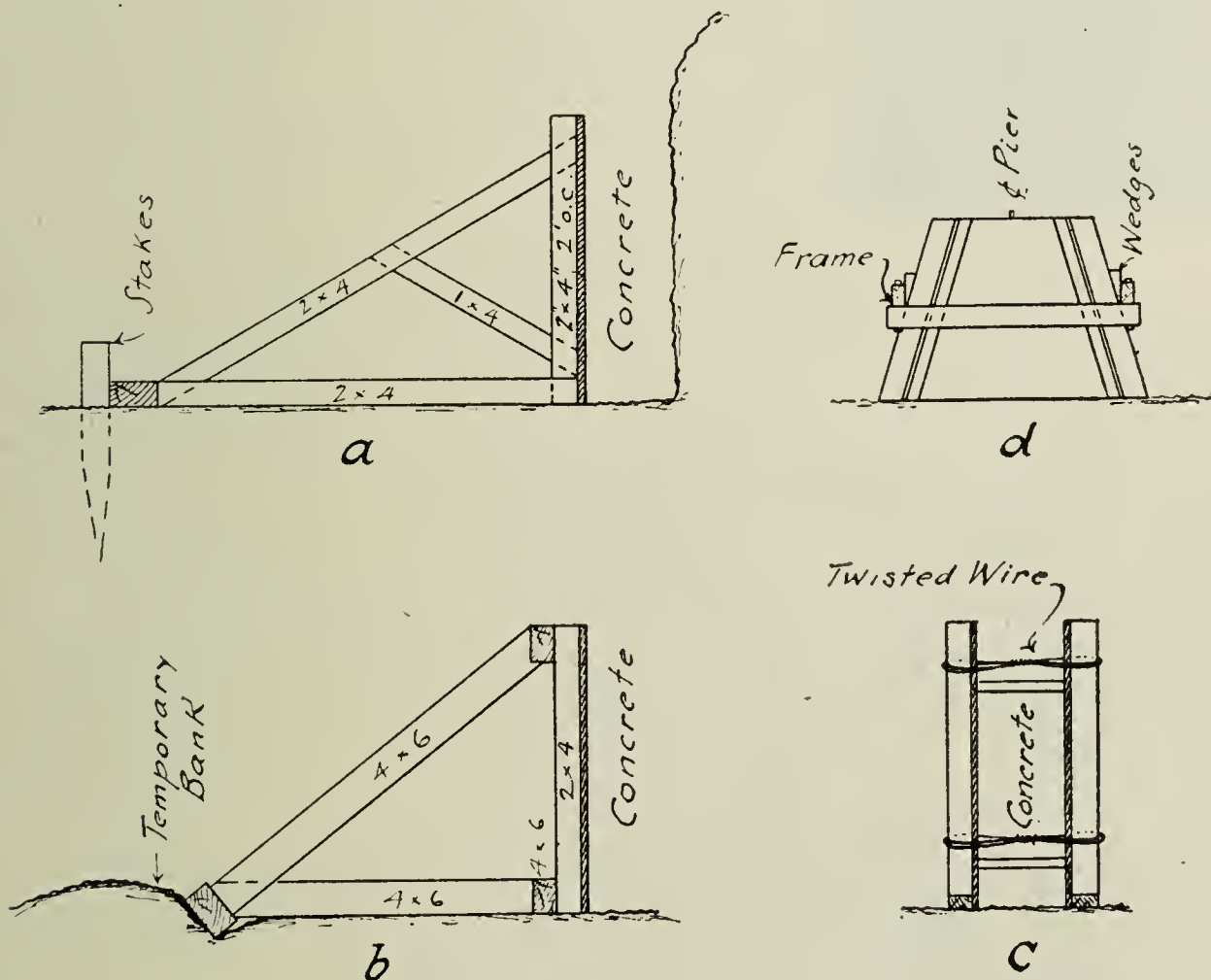


FIG. 6.

Good ties can be made out of oak or chestnut. Impregnated ties are being used to advantage.

It is best to have frog and switch work done by the railroad section crews, while the ordinary track and curves can be done cheaper by the builder.

Form Work, Concrete and Machinery Settings

Tongued and grooved sheathing, 6 in. by $\frac{3}{4}$ in. are frequently used for form work. These latter may be used for roofing, siding or partitions. Tongued and grooved sheathing should not be used where the forms,

after stripping, have to be re-cut to be used over again. The cement gets into the grooves and the boards will have to be cleaned and scraped.

The studding should not be less than 2 ft. apart for $\frac{3}{4}$ in. boards, while with 2 in. boards the studding can be spaced wider. The studding can be of hard wood while the boards should be soft wood to be easily sawed and nailed. Only two nails should be used at the end of each board. It is the studding that gives strength to the form.

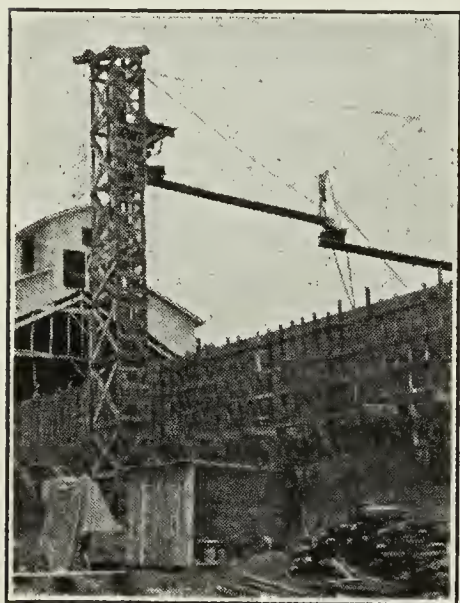


FIG. 7.

For good form work, to be used again, we would recommend 8 in., 10 in. or 12 in. wide boards, dressed, and either $\frac{3}{4}$ in. or $1\frac{3}{4}$ in. according to the size and purpose of form, made of common white pine, yellow pine, spruce, or hemlock. Wide boards save time in handling, in nailing, and in sawing. For studding, 2 in. by 4 in. lumber is customary.

The bracing of the form is most important. If at all possible, the bracing should be carried against a fixed and solid object, like a wall or a foundation. The forms can be braced, as shown in Figs. 6 *a* and *b*. Two parallel forms of a straight wall are best held together by soft steel No. 13 gage wire looped around the studding and then twisted tight as illustrated in Fig. 6 *c*. A pier can be braced by a wedge frame as shown in Fig. 6 *d*.

Edges and corners of exposed concrete work are easily damaged. Outside corners should be beveled and it is desirable to have a fillet in all inside corners.

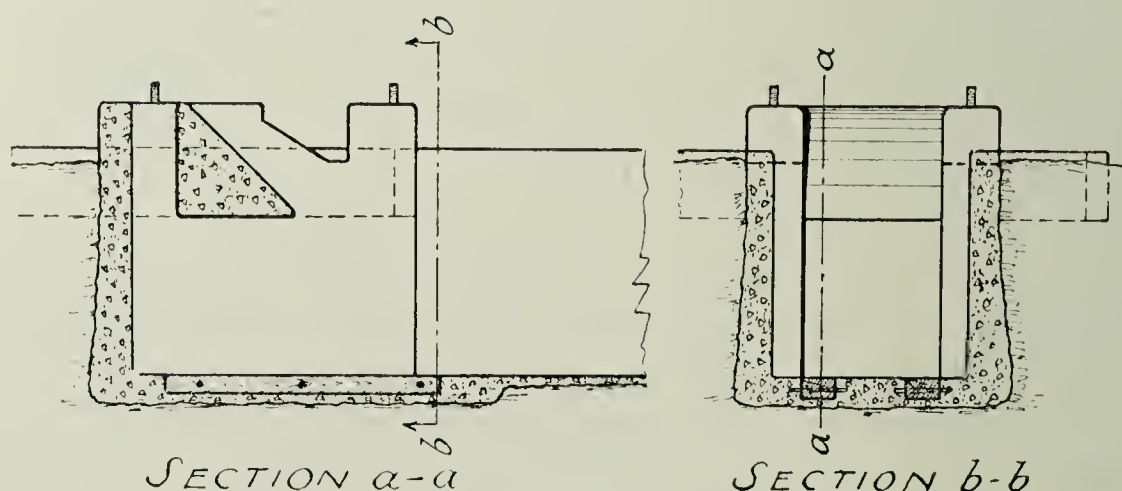


FIG. 8.

The mixture ordinarily used for plain concrete is 2-3-5 (gravel-sand-cement) and for reinforced concrete 1-2-4. Proportioning by shovel is accurate enough. If sand and gravel are obtained mixed, more cement must be used.

On an extensive concrete job it often pays to set up a concrete chuting tower which should be high enough that every corner of all forms can be reached from the end of the chute. The material will slide at an angle of about 25 degrees over the first chute which receives the material at a certain momentum from the hopper while the lower chutes should have an angle of about 30 degrees. Use of water to make the concrete slide the chutes is detrimental to the strength of the wall. Fig. 7 shows bracing and use of chuting tower in construction of reinforced concrete clay storage. This tower was later used for the kiln and kiln building foundations.

On small jobs, it is advisable to move the mixer rather than to lengthen the wheelbarrow hauls.

If the forms are taken off the second or third day, the wall surface may be finished with a wire brush and the corners beveled. Care must be used in stripping the forms too soon since the concrete can easily be damaged.

Fig. 8 is the foundation of a single roll crusher. It provides a concrete hopper and sufficient depth for the conveyor or elevator. The pit is large so as to give easy access to the lower part of crusher and conveyor. The pit is also provided with sleepers, embedded in concrete for holding the tail ends of conveyor or elevator. On each side of the main walls is a shallow pit for the gear on one side and the pulley on the other side, but wide enough to allow sliding them out over the shaft. The anchor bolts are shown solid in concrete.

Fig. 9 shows a pan foundation for a gravity bottom which permits of easy access to the step box. There is an opening through the step box foundation, its top being reinforced. This gives a solid foundation for the step box yet gives almost the same free passage to the material as the steel beam supports. The anchor bolts are to be placed within large pipes fully to the bottom since pan foundation bolts rarely fit just right, the pan being made up of several castings bolted together.

In Fig. 10 is a cross-section through a foundation for an auger machine with its adjacent pit for waste clay conveyor or elevator. The excavation

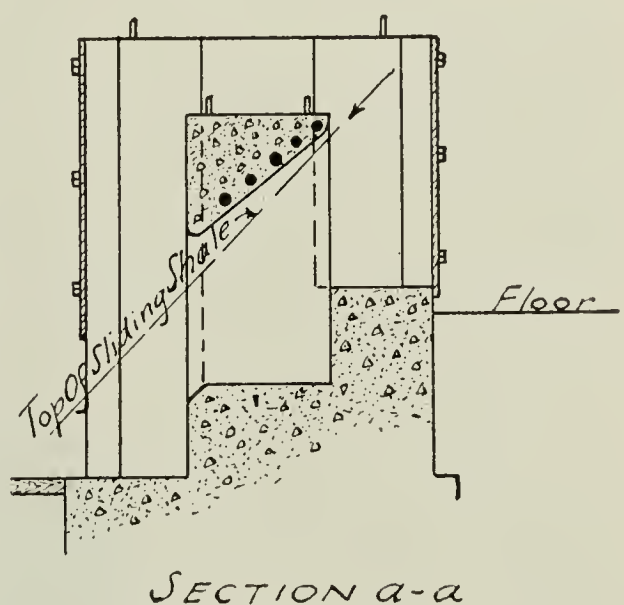
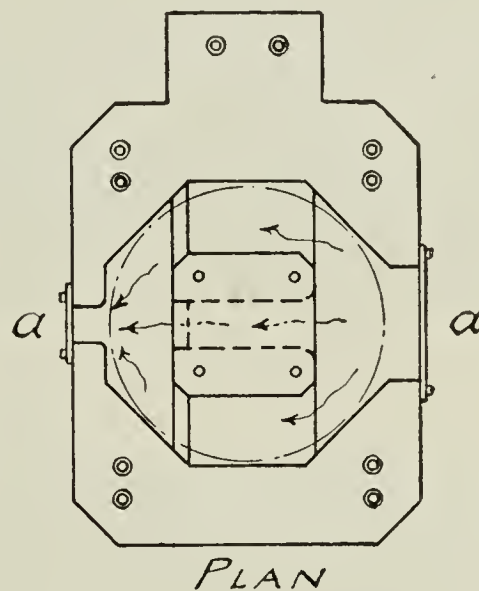


FIG. 9.

next to the pit is carried down fairly plumb to act as form for the machine foundation, and is removed afterwards for the pit.

In Fig. 11 we have a double motor setting for two pans in three different designs. Design "A" was submitted first but rejected since the earth

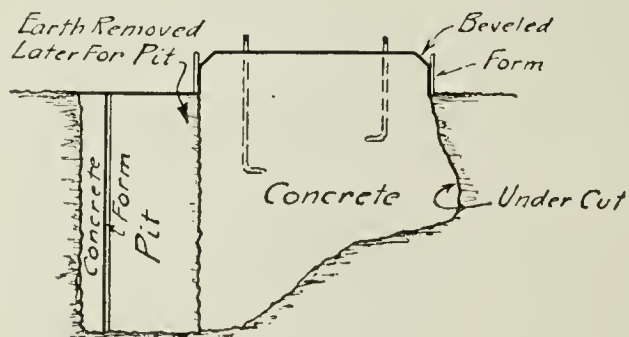


FIG. 10.

inside the form could not be kept in shape and it would also shrink away later. Design "B" treated the foundation as a bridge or a culvert with open passages and a reinforced slab on top. Design "C" was finally adopted. It provides a substantial footing and enough weight to counteract the pull from the two pans. The sketch

is shown so the pull from the motors is against the observer, hence the front and rear of design "C" are battered, which the picture does not bring out.

Kilns and Stacks

A mason will lay a little more than half the number of brick in a kiln as in an ordinary building. The tendency now is towards the use of more common brick in kiln work where formerly No. 2 fire brick was used. For dipped brick with narrow joints, it is essential to select brick of uniform thickness, and it is also important to lay full mortar joints. There is a vast difference in the purpose and treatment of a dwelling and a kiln after completion, and masons, not experienced in kiln work, should be closely watched. The best plan is to build kilns with alternate header and stretcher courses, and not more than two stretcher to one header course should be used.

Drainage is usually necessary and should be covered by specifications. Its extent and necessity depend entirely upon local conditions.

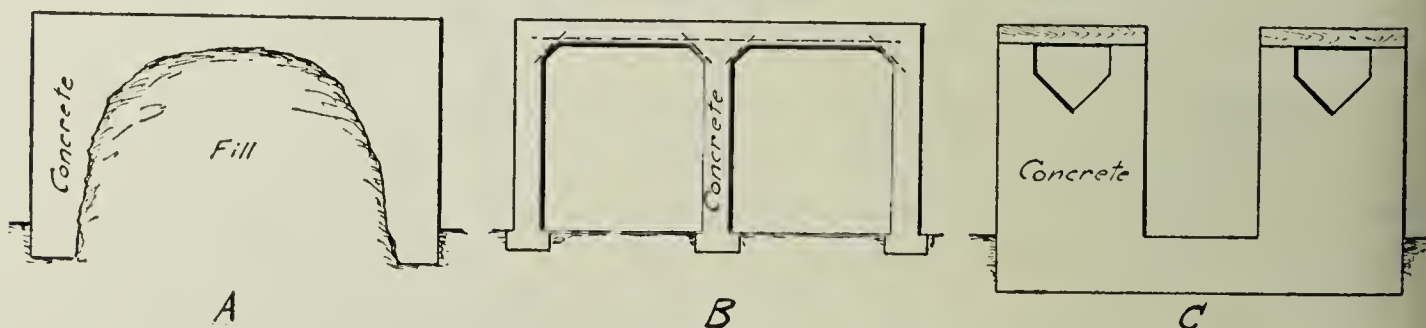


FIG. 11.

Generally speaking, in constructing a kiln, it is best to proceed as follows: Excavate all over to proper depth and lay drains; level up all over with sand; pave all over with one course flat brick; build foundation walls and lower draft flues through foundation; build outside kiln walls complete with furnaces, doors, and crown; build bag wall foundations; build feather walls between bag wall foundations and kiln wall foundation, with proper clearance all around for expansion; lay floor bricks; build furnace bags.

The walls of a round kiln are easily built by means of a sweep, as shown in Fig. 12. The same pole with a different arm, set higher up to correspond with the shape of the crown is being used later as a guide for the circularly set courses of the crown.

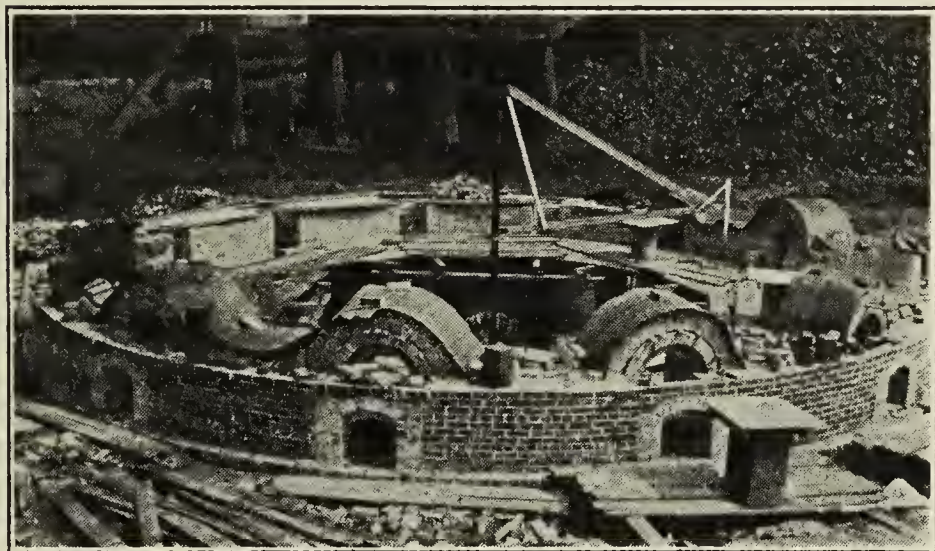


FIG. 12.

The crown of a rectangular kiln or of the chamber of a continuous kiln is erected over a form, consisting of centers and slats, which is set up on bricks or posts and wedged up against the crown to proper level, and is moved along like the smaller forms or centers used on flue arches.

The big band on a round kiln to hold the crown is set up when the wall is high enough to receive the projecting bricks which carry it. The brickwork is set up behind the band but not against it, leaving a layer of mortar for some leeway in expansion.

All brickwork during construction is to be covered over night to prevent rain from washing out the mortar, and to facilitate more uniform hardening and settling over night.

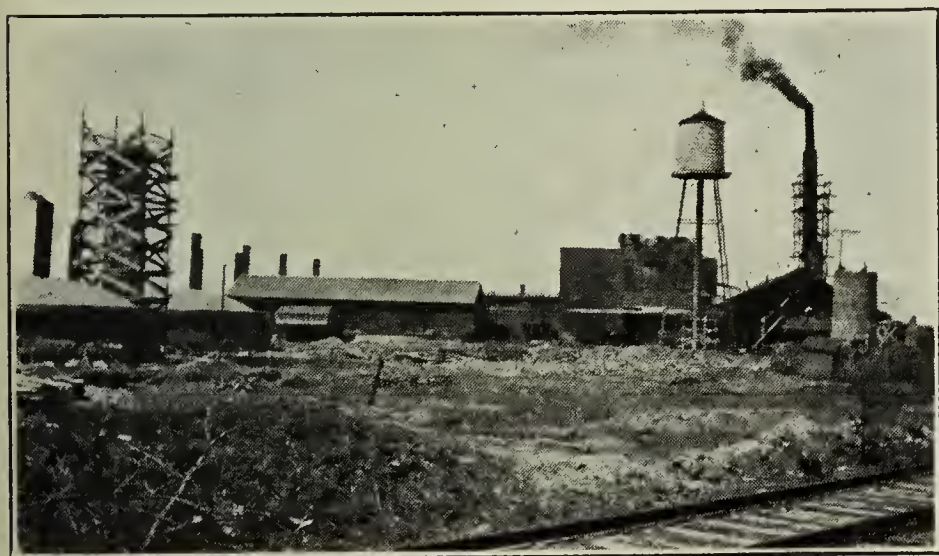


FIG. 13.

Fig. 12 also clearly shows the manner of covering the brick.

Single, double and quadruple stacks with partitions have to be built from the outside by scaffolding while large stacks without partitions for a row of kilns or for power, are erected from the inside.

This is very much faster than with scaffolding from the outside. In Fig. 13 is shown to the left a stack with scaffolding and to the right one that is being built from the inside.

The essentials of a good kiln stack are: solid foundation, independent fire-brick lining, outside brick walls in cement mortar with full joints, and a weatherproof coping.

METHOD OF COOLING ENAMEL BY COMPRESSED AIR

BY A. MALINOVSKY

When the enamel industry was in its infancy the molten mass was air cooled by allowing it to run from the melting furnace onto the iron plates. This hard mass of enamel, so produced, took an unusually long time for grinding and caused terrific wear and tear on the mill linings and stones.

As the enamel industry grew demanding larger mill production water cooling was introduced. This gave the molten mass a chill or quench. By this method the enamel is shattered and made brittle, which in turn shortens the milling time and lengthens the life of the mill linings.

Water cooling is economical in milling but otherwise it has its disadvantages. Brittleness and some of the desirable chemical and physical qualities of the molten mixture are changed. The light pieces and all the soluble ingredients of the opacifying agencies are flushed away. The opacifying power of the costly metal oxides is reduced. In the case of powder enamel, the water cooling involves an extra expensive drying process before grinding.

If, as the molten mass is discharged from the spout of the furnace it is subjected to a stream of compressed air the mass will be so shattered that it will grind easily and yet not have suffered loss of properties or of any of its constituents. The molten stream of enamel will be separated into small particles and blown a sufficient distance to become cooled. The molten enamel is separated into very fine flakes or into threads. This is controllable by the air pressure and is influenced by the viscosity of the enamel. Enamel cooled by compressed air is separated and not shattered and therefore will retain its original chemical and physical strength and will hold its elasticity. Numerous tests and experiments with different steel and castings have shown that fish scaling is thus avoided. It also has proven to be more acid proof, does not easily chip, crack, or blister and withstands blows and shocks better in shipping and use.

It eliminates drying before grinding and the enamel will grind in one seventh of the usual milling time thus increasing the output and lengthening the life of the mill.

On account of its fineness and softness, air cooled enamel can be easily milled on the old type stone mill which produces a more workable cover coat enamel than does the usual ball or pebble mill.

This method has been used at Beaver Dam, Wis., for several years with most satisfactory results in every respect and extensive tests were made on a large scale by the Roesch Enamel Range Co. at Belleville, Ill., with steel and cast iron enamels.

Mr. Tomlinson, petrologist, made reports that there is a decided difference in internal textures of air and water cooled enamels. The air cooled enamel shows a uniform clear glass with a faint color whereas the water

cooled enamel shows swarms of minute globular inclusions with a banding arrangement. These globules would form perhaps a tenth of the mass. It appears like thin emulsion of two immiscible substances.

It is very interesting to know that the two samples examined by Dr. Tomlinson were made from the same batch; half of the fused enamel was let into water, and the other half blown by air.

AIR COOLED VS. WATER QUENCHED ENAMELS

BY STEFAN WIESTER

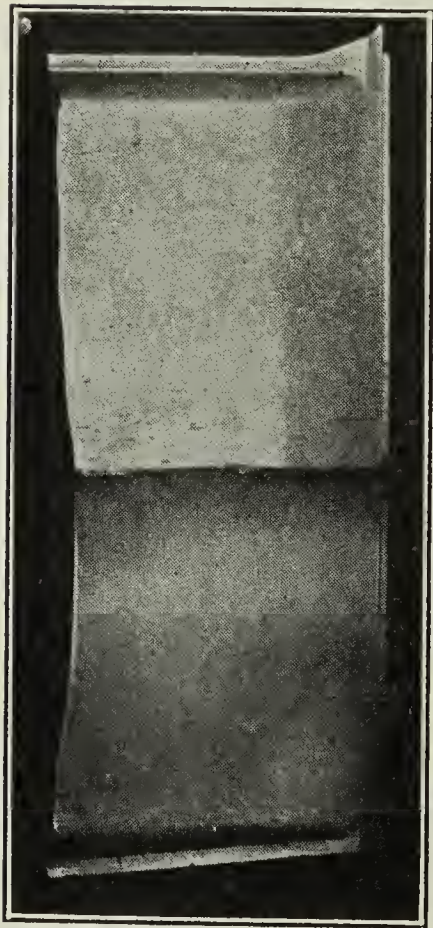
In 1916, at the Malleable Iron Range Company, Beaver Dam, Wis., I was confronted with the problem of making an enamel that would be more resistant to smoke and flue gases and to shocks in mounting and use.



FIG. 1.

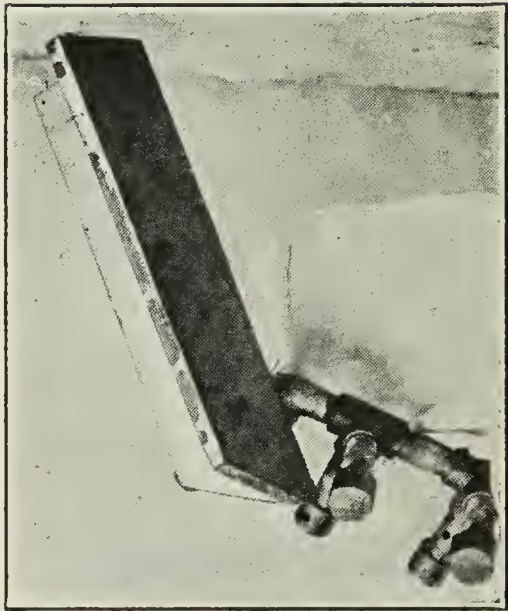
Showing the flow of air-cooled enamel also water tube for water quenching of the tests.

We solved the problem by changing from water to air cooling of the enamel frit. I was anxious to see the wet process work on cast iron so I equipped a small smelter with compressed air containing an enamel used for white

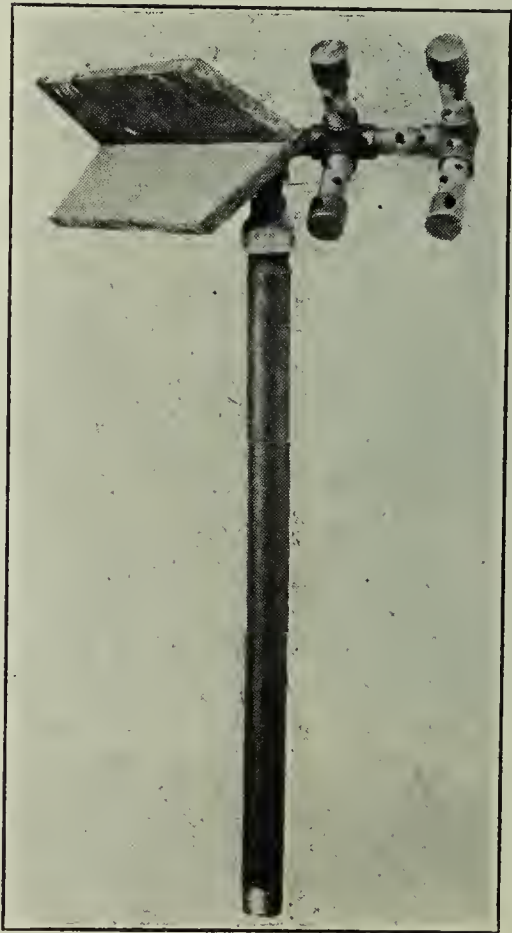


Air cooled.

FIG. 2.



SIDE VIEW.
FIG. 2a.



FRONT VIEW
FIG. 2b.



Air-cooled.

Water-cooled.

FIG. 3.

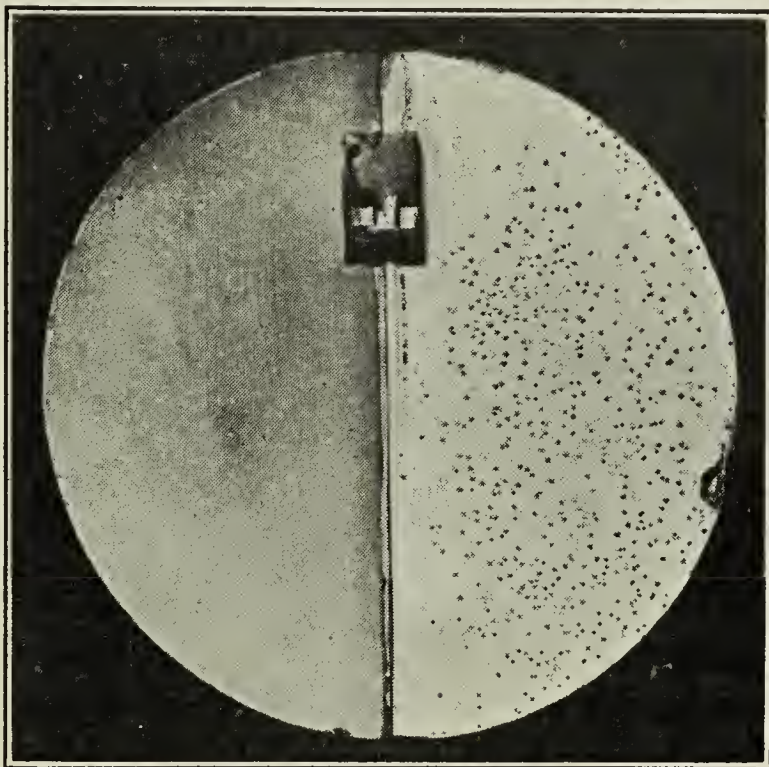
cast iron. Boneash, cryolite and antimony were used as opacifiers for the first coat, and 5% tin oxide enamel for the second coat. The raw batch was 150 lbs. It was smelted for 2 hours 30 minutes. One half of the batch was poured into water and the other half was blown and cooled by air. The enamel was pulverized in 25 pound batches to pass a 60-mesh-sieve easily.

The cast iron was cleaned by sand blasting as usual. The enamel was sprayed. One half showed quite a few gas blisters due to underfiring (the time in burning was 10 minutes at 1200°F). The enamel which blistered was poured into water, the other was air cooled.

Two stove lids were taken from the scrap pile, all rusty. They were sand blasted, sprayed, and fired as usual. The air cooled enamel gave a smoother surface with better opacity and more gloss than did the water cooled enamel.

To cool enamels by compressed air for dry process a longer spout must be used so as to give the enamel some chill before putting under air pressure. The enamel will then stay in fine threads by regulated air pressure. Otherwise the enamel will get too fine.

The enamel can be blown right into a continuous mill and stored in powdered form, thus saving the handling and drying.



Air-cooled.

Water-cooled.

FIG. 4.

SANDBLAST CASTINGS TO BE ENAMELED

BY F. G. JAEGER

Every enameler knows that for successful enameling cast iron must be thoroughly cleaned. This can be accomplished only by sandblasting.

Various types of sandblasting machines are in use for different types

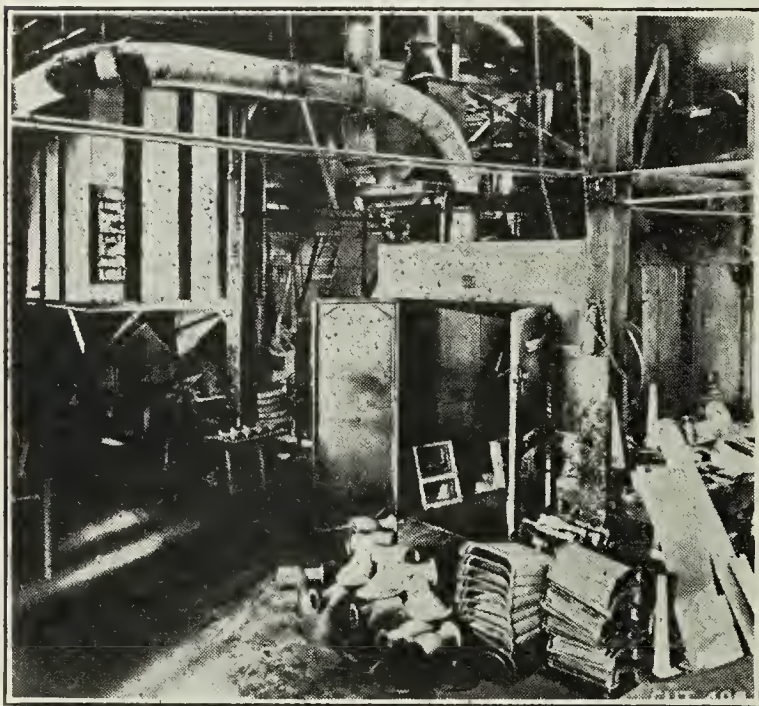


FIG. 1.

of work, but the room type machine is the most advantageous. The tonnage cleaned is determined by the method of handling the work. The hose or nozzle should be kept working as much as possible, as air pressure means horse power and horse power costs money.

The cost per ton varies with the character of the work passing through the sandblast room.

Extensive tests and long experience have shown that the down-draft ventilation of sandblast rooms is most efficient

because it prevents the dust from rising to a height where it would inconvenience the operator or obstruct his view of the work.

The sandblast room shown in Fig. 1 has a double ceiling. The top ceiling has ventilators across the full length of the room, spaced on three-foot centers, while the second ceiling twelve inches below the first is composed of six-inch channel sections with a space between each section, making a slotted ceiling. The air is taken through the ventilators in the upper ceiling. The slotted ceiling distributes this air evenly over the entire area of the room.

The down-draft ventilation has probably done more than any other thing to bring this type of equipment into wide use for sandblasting grey iron castings. While there are many variations on this type, a standard room is one in which one operator may sandblast many tons of castings

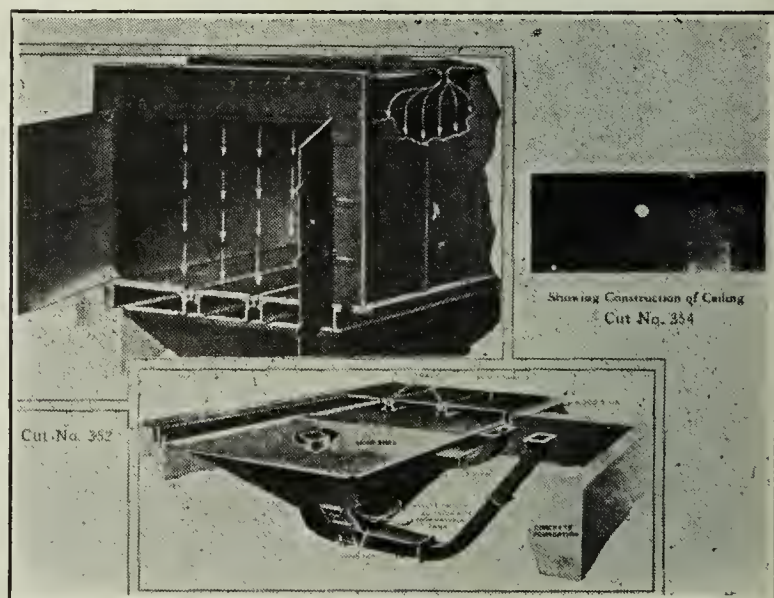


FIG. 2.

in a day. The possibilities are limited only by the size of the room, the industry and skill of the operator and the coöperation he has in handling the work to and from the room.

Fig. 3 shows a sandblast room. A complete installation includes a pressure tank, elevating pipe, sand separator and dust arrester. To save factory space, the dust arrester has been placed outside the building. (The wall has been broken away to show dust arrester in correct position.)

In many cases the work to be sandblasted is placed in the room by hand. Where it is possible a more economical and more speedy method is to use cars. Tracks may be laid from where the work originates into the sandblast room. Other methods such as overhead carrying systems may be utilized.

This sandblast room is made of twelve gage steel plates for walls and ceilings. The lining plates which protect side walls and doors are 40 inches by $1\frac{1}{4}$ -inch. The room has electric illumination with protective reflectors. The floor consists of wrought iron gratings interchangeable and removable sections resting on the heavy floor

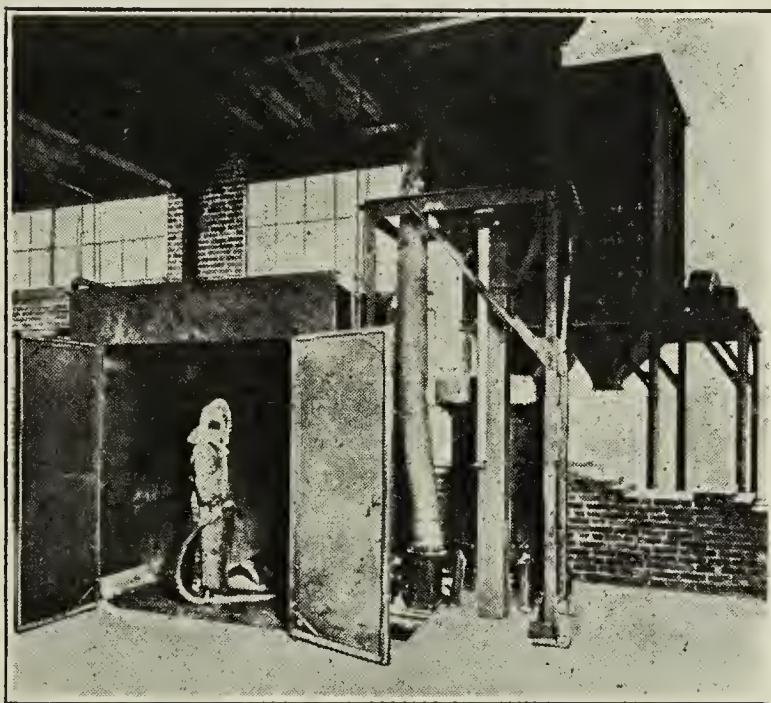


FIG. 3.

beams which also carry the car track. All sand and dust enters the floor hopper through this grating.

The abrasive falls through the floor grating; it is distributed to two inclined screens from which the abrasive and fine material passes to a sand-feeding device at the base of the hopper. Just above the central trough is an agitator consisting of a perforated pipe connected to the pressure tank vent. When the pressure tank is shut off the waste air blows through the perforations in the agitator, and throws the material in the trough back onto the screens for a second screening. The operation of this agitator is automatic and simultaneous with the shutting off of the pressure tank for refilling. It requires no attention. The abrasive and dust is fed from the sand feeding device into the elevating pipe and carried to the sand separator which can be adjusted for single or double separation.

Single operation returns the abrasive to the pressure tank and allows the dust and pulverized abrasive to be carried to the dust arrester. Double separation returns the abrasive to the pressure tank and reclaims the finer sand which is discharged into the pressure tank for re-use. By this method only the dust is carried to the dust arrester.

The arrangement of elevating sand and dust by means of suction created by the ventilating fan eliminates mechanical devices which would be subjected to excessive wear by the abrasive. All elbows of the elevating system and parts lying on a slant are made of $\frac{1}{4}$ -inch steel plate, easily replaceable.

The volume of ventilating air handled in this manner is based on a velocity in a downward direction of about 70 feet a minute. At this rate the air in the operating room is changed about ten times a minute. As it is drawn downward it carries the dust into the intake pipe in the floor hopper and out to the dust arrester. This keeps the room practically free from dust, takes the terror from the job of the operator and generally conforms with factory laws of the different states. This increases the output, because the operator wastes no time waiting for dust to settle.

The construction below the floor is such that only sufficient air passes through the sand elevating pipe to elevate properly the abrasive. The remainder of the air is utilized in removing the dust through a large dust pipe directly to the dust arrester. This arrangement makes it possible to use abrasives of various specific gravities. This is accomplished by means of a regulating valve in the dust pipe. Both of these air exhausts are taken out of the floor hopper beneath the room above the sand screens so that in case the sand screens should become clogged with gagers and lumps of core sand, the ventilation of the room would not be impaired. At just about the points at which the air is taken out of the floor hopper there is an abrasive shed which serves the double purpose of distributing the abrasive over the entire area of the screen at the base of the hopper, and of distributing the outgoing air over the entire floor grating of the room. In this way the downward velocity of the air is uniform throughout the room proper.

We have found, after trying other means, that the best results were obtained by working two men in a shift. While one is sandblasting in the room, the other man is loading a truck with castings. A change of positions is made as soon as all the castings in the room have been sandblasted. The doors are thrown and both men unload the room and reload. The castings are piled on the long table and the man who has been on the outside now takes the place of the one who has finished the load just removed from the room. By this method the idle time between room loads is reduced to a minimum.

A fan discharging 6,000 cubic feet of air per minute is located at the opposite side of the room. This air is drawn through the open roof of the sandblast room. This large volume of air in its downward course does not permit the dust from rising more than two feet from the floor thus giving the sandblast operator a clear view of the work and also making for healthful conditions within the room. The operator wears a helmet and gloves for protection from flying sand. Two men have sandblasted

5,000 pounds of light stove plate castings in eight hours and heavier castings can be sandblasted as rapidly as they can be moved by the men. The air compressor supplying air for the work is a 12 × 12 belt driven machine and has a displacement of 345 cubic feet of air per minute and requires about 65-horse power at 120 pounds pressure or about 51-horse power at eighty pounds pressure. Eighty pounds pressure was used on the work described in this paper.

Experience has shown that electricians' rubber gloves stand up better than any other. The flying sand or shot soon wears the threads with which the leather or canvas gloves are sewed and the gloves are then of no further use. The helmet used by the operator is made of canvas and if no protection is given to the seams the helmet is rendered useless in a few days. The entire front and sides of the helmet are covered with rubber sheeting riveted to the helmet. On the sides and in front of the helmet are holes for ventilation. These are covered by a fine wire screen and in the front opening a piece of celluloid just behind the wire screen prevents dust or fine particles from coming through to the operators' face.

The abrasive used is a very hard dry silica sand.

The sandblast operator after closing the doors adjusts his helmet and is now ready for work. He first secures a firm grip on the hose with one hand and with the other turns on the air and sand valves. Pieces too small to hold are strung on a wire, much the same as on a clothes line, along the long side of the room suspended from hooks close to the ceiling.

The flying sand from the blasting of the larger pieces effectively cleans the small pieces which are hung on the wires after remaining there for several hours. Small castings may be placed in a metal tub or barrel and blasted directly with the hose. After a short time the tub is shaken to turn the pieces over and expose new surfaces to be cleaned. As the castings at or near the top are cleaned they are removed so those further down in the tub or barrel may be cleaned.

Cleaning off enamel from defective pieces is accomplished by using the pieces for a sort of back stop by placing them behind the new work being blasted. The sand which has already cleaned the new pieces strikes those from which the enamel is to be removed. Thus the salvaging of castings for re-enameling is accomplished at a very small cost.

The nozzles used have a $\frac{3}{8}$ -inch opening. A nozzle will last about an hour of continuous use. This should be made of chilled cast iron.

Only the very best rubber lined hose should be used as a cheap hose lasts a very short time.

The wear and upkeep on this type of sand-blasting equipment is very small. Taken as a whole the sandblast room covers a more varied number of uses than any other type of cleaning equipment for this purpose.

THE MECHANICAL STRENGTH OF GLAZING GLASS¹

BY ARTHUR E. WILLIAMS

ABSTRACT

Approximately 5,000 samples of glazing glass of various types have been tested for strength with transverse loading and under impact. Modulus of rupture, modulus of elasticity, impact modulus of rupture, stress strain curve, and actual values required for breaking glass are shown.

The comparative results are shown on 13 different diagrams. These indicate the following values may be used for modulus of rupture for calculating the strength of these various types of glass.

	Modulus of rupture pounds per square inch
Single strength and double strength window glass and 26 oz. clear sheet glass	7,000
29 oz. to 39 oz. clear sheet glass and $\frac{1}{4}$ " plate glass	6,500
Rolled sheet and wire glass	6,500
Ribbed rolled sheet and wire glass	5,300
Corrugated wire glass 1" deep	13,500
Corrugated wire glass $\frac{3}{4}$ " deep	9,500
Values for Young's modulus for various types of glass (in pounds per square inch)	
Single and double strength window glass	11,000,000
26 oz. to 39 oz. clear sheet glass	10,500,000
Polished plate glass	10,000,000
Rough rolled glass	970,000
Nonscatterable glass (varies greatly with thickness) $\frac{3}{16}$ "	16,670,000
$\frac{7}{8}$ "	550,000

Introduction

Information showing the relative strengths of the various types of glazing glass commonly used is rather meager and based on tests of a few samples. A method of testing which can be carried out in a simple manner on small samples of glass is also desirable. The following is a preliminary report of work being done to provide such information, especially with reference to correlating tests on small samples with values obtainable on large sheets of glass mounted in a frame.

Several types of glazing glass are produced and these are made in various thicknesses and by various methods of manufacture. A classification of glazing glass is therefore shown below to indicate the variety of types marketed.

Types of Glass Tested

Approximately 5,000 samples have been tested to provide the results shown in this paper. These samples consisted of various thicknesses of

¹ By permission of the Director of the Bureau of Standards, Department of Commerce. Presented before the Glass Division, Pittsburgh Meeting, February, 1923. For Discussion see *Bull. Amer. Ceram. Soc.*, 2 [8], 294 (1923).

CLASSIFICATION OF GLASS FOR GLAZING PURPOSES

Polished Plate Glass	{	Second silvering quality	
		Glazing quality	
Clear Sheet or Window Glass	{	Single strength	{ A quality
			B quality
	{	Double strength	{ A quality
			B quality
	{	Heavy sheet	{ Glazing quality
			Factory run
Processed Glass	{	Chipped	{ No. 1 Processed
			No. 2 Processed
	{	Ground	{ Acid ground
			Sand blasted
Rolled Figured Sheet	{	Figured sheet	{ Large variety of
		Colored figured sheet	patterns
Wire Glass	{	Polished wire	
		Polished (one side)	
	{	Figured	
		Corrugated	
		Colored	
Ornamental Plate		Figured plate (polished one side)	
Prism Glass	{	Pressed tile	
		Rolled	

window and clear sheet glass, polished plate glass, processed glass, rolled figured sheet, wire glass and non-scatterable glass. In two cases the samples represented three and five days' consecutive run of two different manufacturers, thus indicating the probable variation in strength likely to appear in a single manufacturer's goods.

Values Determined by Tests

The various factors determined were the actual load required to cause rupture of samples supported on two ends and loaded in the center, the energy required to break samples supported in the same manner when struck a sudden blow and the deflection produced on slow loading. From these values have been calculated the modulus of rupture, Young's modulus of elasticity and an impact modulus of rupture. Stress strain diagrams have been prepared and the elastic properties of the glass up to the breaking point have been determined.

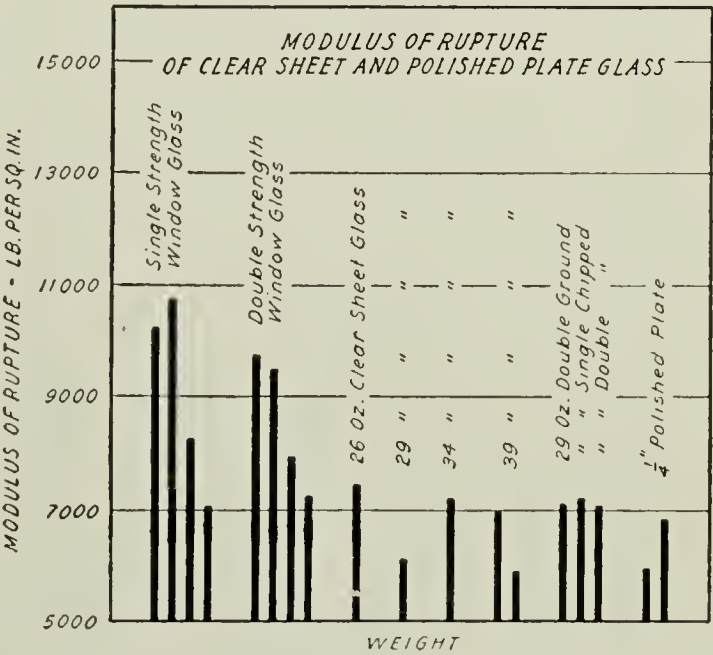


FIG. 1.

Methods of Testing

Transverse Tests of Small Samples.—Transverse strength was determined on samples $18" \times 2"$ using a 16-inch span and loading in the center.

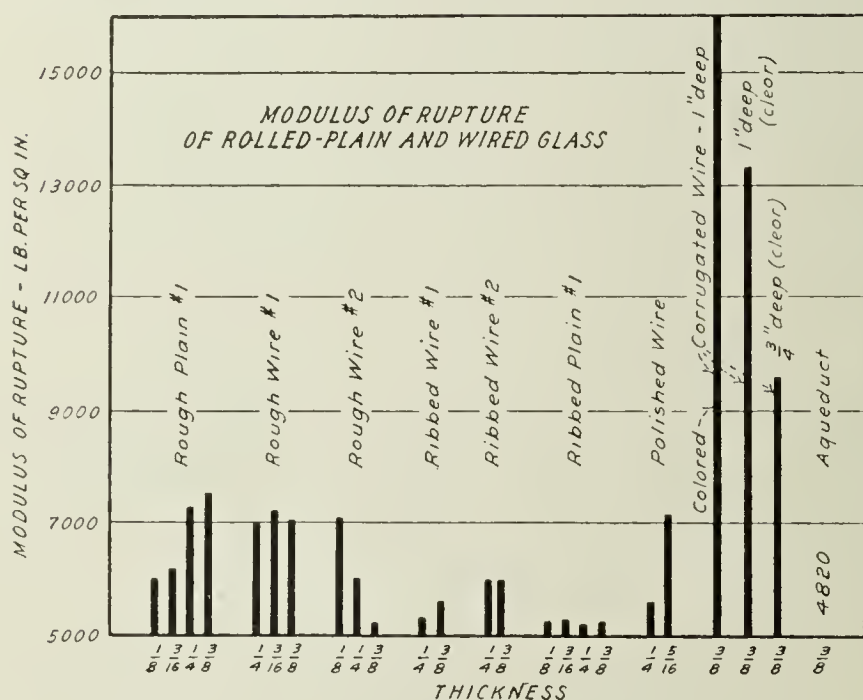


FIG. 2.

The load was applied by shot at a rate of 10 pounds per minute for all window and clear sheet glass and $\frac{1}{8}$ -inch rolled glass and at a rate of 15 pounds per minute for all heavier glass. Deflection was measured by use of an Ames dial reading to .001 inch placed on the point of application of the load.

The slow rate of loading used was found, as a result of experiments, to be necessary

to obtain consistent results, as the actual loads required to produce rupture were never very great.

Impact Tests of Small Samples.—The samples tested were 18 inches long and 2 inches wide, the thickness varying as shown in the charts in which the results are presented. The impact was delivered by means of a pendulum, the tup of which was of hardened steel in the form of a disc $1\frac{1}{2}$ inches in diameter and $\frac{9}{16}$ inch thick, with the edge rounded to conform to the surface of a sphere with the same center and diameter as the disc. The weight of the tup was 6 ounces. The specimen, in position for testing, was held with one broad side against two heavy vertical supports of cast iron, so spaced as to provide a 16-inch span. A dial was prepared, graduated in divisions equal to a blow of .025 ft. lb. and in breaking the glass, the pendulum was raised to an angle equal to 0.1 ft. lb. and the tup attached to a magnet held in the proper position.

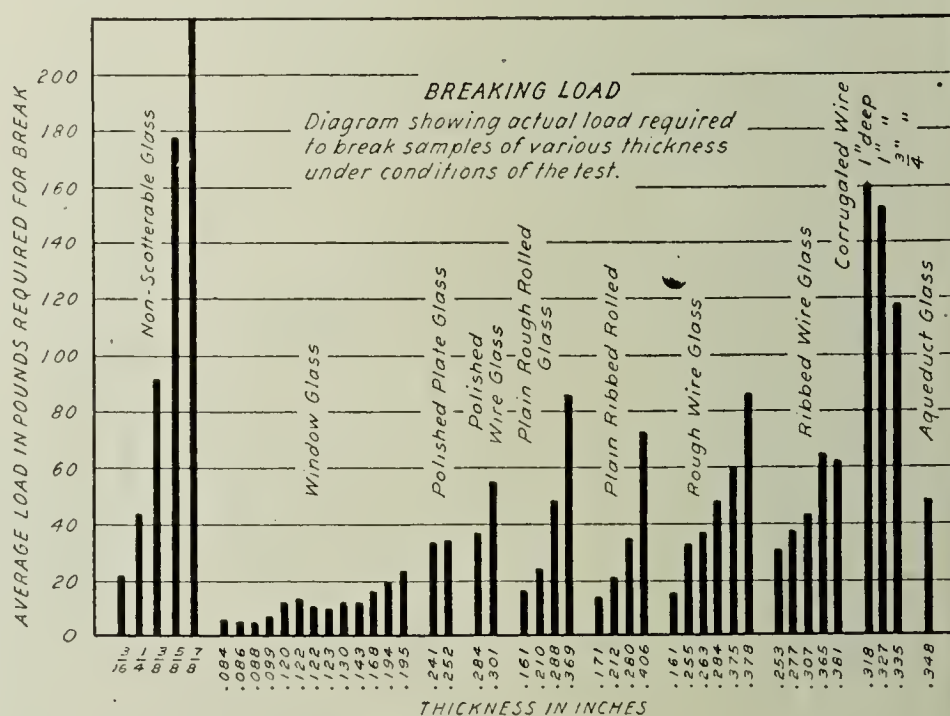


FIG. 3.

TABLE I
DETAILED RESULTS OF TESTS

Factory Number	Style of Glass	Number of Pieces Tested	Average Modulus of Rupture	Average Variation from Mean Modulus	Per Cent Variation from Mean Modulus	Average Modulus of Elasticity	Average Variation from Mean Elasticity	Per Cent Variation from Mean Elasticity	Average Deflection	Average Load	Maximum Thickness	Minimum Thickness	Average Thickness	Number of Pieces Tested	Actual Impact	Average Impact for One Inch Thickness	Maximum Thickness	Minimum Thickness	Average Thickness	Impact Modulus of Rupture
4	3/16" Nonscatterable	10	8750	928	10.6	1667×10 ⁴	21×10 ⁴	1.26	0.134	22.08	0.185	0.160	0.179	10	0.340	1.87	0.203	0.162	0.1785	1494
4	1/4" " "	10	9500	905	9.5	1383×10 ⁴	55×10 ⁴	3.96	.130	44.04	.262	.211	.238	10	.457	1.93	.240	.228	.2365	1370
4	3/8" " "	10	7750	955	12.3	921×10 ⁴	35×10 ⁴	3.80	.095	92.20	.406	.369	.374	10	.427	1.16	.400	.302	.3740	843
4	5/8" " "	10	5750	447	7.7	790×10 ⁴	64×10 ⁴	8.07	.052	177.4	.640	.576	.608	8	.545	0.95	.600	.560	.5539	760
4	7/8" " "	9	6520	713	10.9	565×10 ⁴	33×10 ⁴	6.55	.052	419.8	.889	.829	.835	7	1.036	1.11	.920	.795	.8356	628
Window Glass																				
5	A Grade Single Strength	65	10020	1950	15.6	1159×10 ⁴	70×10 ⁴	6.00	.423	6.4	.100	.065	.084	8	.159	1.78	.097	.086	.095	1148
6	" " " "	74	10770	880	10.2	1159×10 ⁴	31×10 ⁴	2.67	.317	5.0	.093	.083	.086	8	.159	1.88	.087	.083	.085	1236
7	" " " "	10	8275	460	5.5	1239×10 ⁴	72×10 ⁴	5.81	.338	4.9	.093	.071	.088	8	.147	1.67	.097	.076	.087	1213
7	B " " " "	7	7030	367	5.2	1071×10 ⁴	48×10 ⁴	4.48	.287	6.9	.116	.090	.099	7	.100	1.01	.091	.083	.086	935
5	A " Double "	70	9692	1289	14.9	1041×10 ⁴	46×10 ⁴	4.50	.290	10.8	.130	.121	.120	8	.162	1.29	.135	.120	.125	1061
6	" " " "	76	9442	1167	12.3	1125×10 ⁴	30×10 ⁴	2.60	.316	12.37	.131	.115	.122	7	.136	1.09	.126	.119	.123	755
7	" " " "	8	7880	1567	16.1	1200×10 ⁴	116×10 ⁴	9.68	.297	9.5	.132	.117	.122	6	.154	1.13	.140	.109	.117	1054
7	B " " " "	9	7166	2657	33.3	1134×10 ⁴	19×10 ⁴	1.68	.269	9.4	.122	.108	.123	8	.194	1.26	.137	.125	.130	1098
5	26 Ounce	10	7460	1091	11.8	1069×10 ⁴	21×10 ⁴	1.96	.213	10.8	.148	.129	.130	8	.169	1.29	.142	.121	.131	985
5	29 "	10	6111	391	6.4	1053×10 ⁴	37×10 ⁴	3.51	.190	10.8	.150	.138	.143	8	.198	1.38	.152	.141	.143	1022
5	34 "	10	7230	474	6.5	1045×10 ⁴	48×10 ⁴	4.59	.182	15.2	.173	.163	.168	8	.184	1.14	.170	.160	.162	912
5	39 "	10	6980	725	10.3	1053×10 ⁴	85×10 ⁴	8.07	.151	22.2	.198	.186	.194	8	.222	1.15	.197	.185	.192	925
6	" "	10	5970	647	11.1	1090×10 ⁴	37×10 ⁴	3.39	.127	18.8	.199	.189	.195	7	.186	1.01	.190	.180	.183	886
5	Chipped No. 1	9	7270	481	6.6	1180×10 ⁴	39×10 ⁴	3.31	.201	11.4	.149	.131		7	.143	0.99	.152	.143	.145	865
5	" No. 2	8	7130	602	7.6	640×10 ⁴	30×10 ⁴	4.69	.280	5.7	.130	.116		8	.119	0.96	.131	.111	.125	655
5	Double Ground 29 oz.	10	7040	380	5.4	1065×10 ⁴	16×10 ⁴	1.49	.211	11.9	.150	.128		8	.169	1.17	.156	.136	.144	904
8	1/4" Polished Plate	9	6027	289	4.7	965×10 ⁴	30×10 ⁴	3.12	.109	33.0	.260	.247	.241	9	.175	0.68	.260	.247	.255	671
9	" " "	9	6977	675	12.5	1030×10 ⁴	56×10 ⁴	5.43	.124	33.4	.244	.238	.252	9	.225	1.05	.247	.243	.244	821
1	1/8" Plain Rough Rolled	23	5875	550	9.3	1050×10 ⁴	67×10 ⁴	6.3	.143	15.24	.188	.155		24	.113	0.664	.184	.156	.172	696
		23	6050	503	8.2	1063×10 ⁴	48×10 ⁴	4.5	.158	15.80	.180	.156		17	.116	.697	.178	.158	.167	720
		25	5960	431	7.2	1015×10 ⁴	64×10 ⁴	6.3	.151	15.48	.189	.162		24	.111	.630	.188	.165	.177	667
		24	6070	589	9.7	980×10 ⁴	48×10 ⁴	4.9	.151	15.80	.195	.161		26	.107	.604	.200	.162	.179	642
		23	5920	547	9.2	1030×10 ⁴	46×10 ⁴	4.4	.142	15.48	.189	.163		23	.100	.557	.190	.167	.180	634
	General Average		5975	524	8.7	1027×10 ⁴	54×10 ⁴	5.3	.149	15.56	.188	.159	.161		.109	.632	.188	.162	.178	667
1	3/16" Plain Rough Rolled	9	7050	981	13.9	1000×10 ⁴	29×10 ⁴	2.9	.135	23.40	.222	.177		6	.129	.608	.226	.190	.212	654
		25	5500	549	9.9	990×10 ⁴	63×10 ⁴	6.3	.117	20.76	.228	.196		24	.112	.698	.236	.207	.219	599
		24	5840	439	7.5	992×10 ⁴	43×10 ⁴	4.6	.121	22.20	.221	.203		12	.135	.640	.230	.198	.212	666
		24	6240	405	6.4	1009×10 ⁴	50×10 ⁴	4.9	.126	24.60	.229	.202		25	.122	.572	.234	.200	.213	638
		23	6150	429	6.9	991×10 ⁴	64×10 ⁴	6.4	.136	21.40	.230	.197		25	.135	.637	.227	.198	.212	669
	General Average		6156	560	8.9	996×10 ⁴	49×10 ⁴	4.9	.127	22.47	.226	.195	.210		.127	.611	.231	.199	.213	645
1	1/4" Plain Rough Rolled	23	8120	1323	16.3	1011×10 ⁴	49×10 ⁴	4.8	.121	54.60	.311	.255		15	.330	1.190	.320	.230	.281	914
		25	7725	1312	16.9	995×10 ⁴	48×10 ⁴	4.8	.119	49.40	.328	.232		24	.263	0.938	.306	.238	.270	826
		23	6900	763	11.0	1021×10 ⁴	189×10 ⁴	10.7	.109	42.20	.310	.241		25	.210	.873	.308	.242	.272	745
		22	7275	870	11.9	1045×10 ⁴	57×10 ⁴	5.4	.115	43.80	.322	.243		25	.247	.883	.308	.243	.277	809
		21	8625	1303	15.1	983×10 ⁴	26×10 ⁴	2.6	.127	57.00	.315	.253		25	.212	.698	.327	.264	.305	693
	General Average		7729	1114	14.2	1011×10 ⁴	74×10 ⁴	7.3	.118	49.40	.317	.245	.288		.250	.916	.314	.243	.281	795
1	3/8" Plain Rough Rolled	14	7120	703	9.7	941×10 ⁴	44×10 ⁴	4.6	.088	84.20	.382	.352		23	.313	.825	.389	.355	.374	744
		24	7120	898	12.6	952×10 ⁴	56×10 ⁴	5.8	.090	80.60	.380	.340		25	.324	.858	.388	.344	.372	764
		24	8210	970	11.8	994×10 ⁴	60×10 ⁴	6.0	.096	92.60	.385	.349		25	.315	.866	.390	.352	.367	774
		25	7610	1218	16.0	972×10 ⁴	54×10 ⁴	5.5	.090	83.80	.387	.340		25	.281	.771	.389	.340	.366	724
		23	7420	1588	21.4	924×10 ⁴	88×10 ⁴	9.6	.099	82.60	.389	.344		24	.280	.787	.387	.340	.368	705
	General Average		7496	1075	14.3	956×10 ⁴	61×10 ⁴	6.4	.093	84.76	.385	.345	.369		.302	.821	.389	.346	.369	742

Factory Number	Style of Glass	Number of Pieces Tested	Average Modulus of Rupture	Average Variation from Mean Modulus	Per Cent Variation from Mean Modulus	Average Modulus of Elasticity	Average Variation from Mean Elasticity	Per Cent Variation from Mean Elasticity	Average Deflection	Average Load	Maximum Thickness	Minimum Thickness	Average Thickness	Number of Pieces Tested	Actual Impact	Average Impact for One Inch Thickness	Maximum Thickness	Minimum Thickness	Average Thickness	Impact Modulus of Rupture
1	1/8" Plain Ribbed Rolled	15	5719	499	8.7	1063×10 ⁴	57×10 ⁴	5.3	.149	13.24	.186	.150		24	.080	.825	.183	.155	.168	597
		25	4923	260	5.2	1040×10 ⁴	32×10 ⁴	3.1	.125	12.24	.189	.160		24	.074	.437	.191	.160	.172	561
		25	5420	676	10.6	993×10 ⁴	38×10 ⁴	3.8	.148	13.80	.187	.159		25	.099	.573	.188	.154	.173	632
		24	5040	310	6.1	965×10 ⁴	54×10 ⁴	5.6	.142	12.72	.187	.153		25	.104	.602	.201	.150	.172	640
		25	5100	264	5.2	1015×10 ⁴	42×10 ⁴	4.1	.132	13.00	.189	.154		25	.104	.602	.201	.150	.172	640
		General Average	5240	402	7.2	1015×10 ⁴	45×10 ⁴	4.4	.137	13.00	.188	.155	.171	24	.083	.477	.195	.160	.177	579
1	3/16" Plain Ribbed Rolled	24	5500	525	9.5	997×10 ⁴	60×10 ⁴	6.2	.116	18.00	.222	.182		25	.100	.509	.215	.180	.196	599
		25	5278	352	6.8	1015×10 ⁴	29×10 ⁴	2.8	.109	20.60	.249	.202		18	.104	.545	.243	.203	.221	579
		25	5340	314	5.8	1029×10 ⁴	38×10 ⁴	3.7	.109	20.60	.230	.192		21	.122	.563	.230	.209	.218	637
		24	5330	445	8.3	1025×10 ⁴	54×10 ⁴	5.3	.107	21.00	.226	.198		23	.111	.506	.234	.207	.218	669
		25	4971	239	4.8	971×10 ⁴	49×10 ⁴	5.0	.107	19.80	.238	.202		22	.100	.445	.237	.204	.215	563
		General Average	5283	375	7.6	1007×10 ⁴	46×10 ⁴	4.6	.109	20.00	.235	.195	.212	22	.107	.513	.232	.201	.214	595
1	1/4" Plain Ribbed Rolled	25	5208	502	9.6	978×10 ⁴	85×10 ⁴	8.7	.085	34.24	.299	.261		25	.122	.422	.312	.244	.290	538
		25	5233	734	12.0	1033×10 ⁴	142×10 ⁴	13.6	.079	34.60	.309	.250		25	.116	.422	.306	.250	.275	562
		25	5382	725	13.4	979×10 ⁴	132×10 ⁴	13.5	.082	36.00	.310	.272		25	.115	.435	.300	.250	.274	538
		22	5135	202	3.8	1044×10 ⁴	105×10 ⁴	9.5	.071	31.00	.306	.257		25	.110	.407	.300	.243	.274	543
		15	4671	272	5.9	964×10 ⁴	87×10 ⁴	9.0	.077	31.80	.296	.258		25	.111	.402	.295	.257	.276	522
		General Average	5151	487	8.9	999×10 ⁴	110×10 ⁴	10.8	.079	33.53	.304	.260	.280	25	.116	.418	.303	.249	.278	541
1	3/8" Plain Ribbed Rolled	25	5450	324	5.7	910×10 ⁴	46×10 ⁴	5.0	.064	75.00	.433	.356		25	.208	.516	.428	.361	.403	575
		25	5500	539	9.8	883×10 ⁴	86×10 ⁴	9.7	.068	75.40	.424	.386		23	.196	.503	.415	.394	.407	547
		25	5420	406	7.4	843×10 ⁴	37×10 ⁴	4.4	.068	77.00	.427	.393		22	.220	.545	.427	.398	.412	562
		15	4825	403	8.3	867×10 ⁴	75×10 ⁴	8.6	.060	66.60	.424	.397		23	.189	.462	.424	.397	.411	531
		20	5260	484	9.2	839×10 ⁴	52×10 ⁴	6.2	.065	73.00	.420	.386		24	.197	.468	.427	.395	.409	533
		General Average	5291	431	8.0	868×10 ⁴	59×10 ⁴	6.7	.065	73.40	.426	.384	.406	24	.202	.499	.424	.389	.408	549
3	1/4" Polished Wire	10	5569	1148	20.3	1031×10 ⁴	62×10 ⁴	6.0	.093	37.12	.295	.275	.284	7	.122	.426	.301	.287	.298	545
1	5/16" Polished Wire	25	6909	817	11.8	1031×10 ⁴	62×10 ⁴	6.2	.096	55.80	.328	.260		25	.240	.790	.339	.260	.311	749
		25	7470	810	10.8	982×10 ⁴	44×10 ⁴	4.4	.108	55.40	.351	.260		25	.237	.749	.356	.282	.306	729
		24	7130	726	10.1	1025×10 ⁴	34×10 ⁴	3.3	.104	55.80	.342	.249		25	.225	.719	.350	.249	.295	741
		23	7035	947	13.5	945×10 ⁴	36×10 ⁴	3.8	.101	50.60	.349	.262		25	.266	.813	.360	.280	.309	756
		25	7087	894	11.0	987×10 ⁴	55×10 ⁴	5.5	.105	55.40	.355	.269		25	.312	.639	.340	.258	.308	839
		General Average	7126	839	11.4	994×10 ⁴	46×10 ⁴	4.6	.103	54.60	.345	.260	.301	25	.256	.742	.349	.266	.306	765
2	1/8" Rough Rolled Wire	1	25	7900	844	11.4	1705×10 ⁴	87×10 ⁴	3.1	.127	14.60	.165	.141	26	.103	.651	.165	.141	.152	901
		2	25	7570	1020	13.5	1596×10 ⁴	149×10 ⁴	9.3	.133	14.20	.158	.145	25	.108	.642	.194	.140	.165	857
		3	24	5900	548	7.5	1051×10 ⁴	85×10 ⁴	8.1	.129	15.00	.187	.170	24	.101	.589	.186	.161	.178	776
		General Average	25	7123	804	10.8	1450×10 ⁴	107×10 ⁴	7.5	.130	14.60	.170	.152	.161	25	.104	.627	.182	.147	.165	845
2	1/4" Rough Rolled Wire	1	23	5640	403	7.1	989×10 ⁴	74×10 ⁴	7.5	.097	28.20	.268	.241	24	.133	.533	.268	.241	.256	576
		2	24	5850	248	4.0	997×10 ⁴	59×10 ⁴	5.9	.098	30.20	.275	.247	25	.137	.514	.273	.245	.259	609
		3	24	6260	533	8.6	1003×10 ⁴	64×10 ⁴	6.4	.098	37.00	.265	.235	29	.153	.591	.271	.246	.259	646
		General Average		5920	395	6.6	996×10 ⁴	66×10 ⁴	6.6	.098	31.80	.269	.241	.255		.141	.546	.271	.244	.257	610
2	1/4" Rough Rolled Wire	81	6430	770	11.9	996×10 ⁴	50×10 ⁴	5.0	.102	37.00	.276	.251	.263	71	.180	.649	.280	.255	.264	699
1	1/4" Rough Wire	23	6820	880	11.1	985×10 ⁴	38×10 ⁴	3.8	.105	44.20	.316	.256		26	.166	.586	.310	.250	.277	645
		14	6853	1298	18.9	1028×10 ⁴	78×10 ⁴	7.6	.107	46.20	.316	.271		23	.148	.557	.305	.260	.278	620
		23	6860	684	9.9	990×10 ⁴	33×10 ⁴	3.3	.103	48.60	.300	.262		13	.190	.621	.306	.258	.283	684
		24	6950	821	11.8	1025×10 ⁴	48×10 ⁴	4.6	.103	49.40	.308	.272		25	.191	.680	.303	.267	.288	691
		25	7204	1024	14.2	999×10 ⁴	32×10 ⁴	3.2	.108	52.20	.308	.282		23	.187	.644	.312	.269	.297	665
		General Average		6937	941	13.2	1005×10 ⁴	45×10 ⁴	4.5	.105	48.12	.309	.269	.284		.176	.618	.307	.261	.284	661
1	3/8" Rough Wire	15	6860	880	12.8	952×10 ⁴	45×10 ⁴	4.7	.087	79.80	.390	.331		22	.204	.524	.390	.327	.362	614
		23	7040	898	12.7	985×10 ⁴	74×10 ⁴	7.5	.085	84.60	.412	.352		26	.220	.585	.414	.355	.379	634
		24	7280	673	9.3	956×10 ⁴	81×10 ⁴	8.7	.084	93.16	.415	.357		25	.195	.498	.407	.357	.379	588
		25	6515	1019	15.6	989×10 ⁴	50×10 ⁴	5.2	.086	85.00	.403	.353		24	.210	.592	.400	.352	.373	626
		24	7162	998	13.9	955×10 ⁴	57×10 ⁴	5.7	.082	85.16										

The tup was then released from the magnet so that it struck the glass at right angles to the plane of the sample. Repeated blows were struck with forces increasing in increments of .025 ft. lb. until a break occurred.

Results of Tests

The accompanying Table I shows in detail the results obtained from both tests. It indicates the amount of variation which may be expected from such tests and in case of the rough rolled and wire glass, the variation of the product of a factory from day to day is also shown.

The diagrams shown in Figs. 1, 2, 3 and 6 compare with the values obtained for modulus of rupture and the actual loads required to break the test specimens. Where more than one value is given in the diagrams for the same type and thickness of glass, each value represents that obtained for the product of a different manufacturer. The values obtained for modulus of elasticity (Young's modulus) shown in Figs. 4, 5 and 6 are

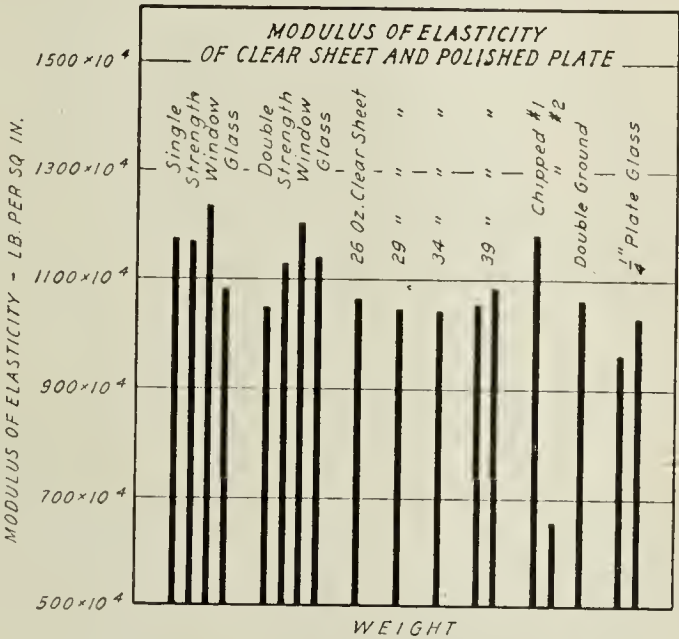


FIG. 4.

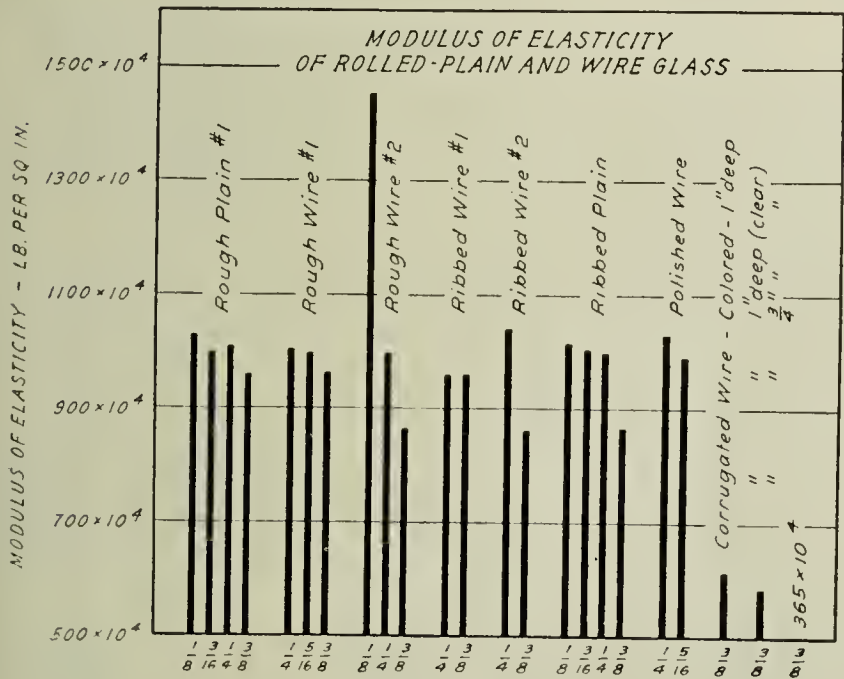


FIG. 5.

calculated, using the deflection values and loads obtained in the crossbreaking tests. The thicknesses shown in Figs. 1, 2, 4, 5 and 6 are the trade thicknesses of the glass, the thicknesses shown in Figs. 3, 7 and 8 are the actual thicknesses found, and aid in getting a true comparison of the strength. The results of impact tests are shown in Figs. 7, 8 and 9. An attempt has been made to express these results on a

basis of the strength of the material with respect to unit thickness. A comparison obtained by a direct calculation of the proportionate strength of samples one inch thick is shown in Fig. 8, and a comparison on the basis of an impact modulus is shown in Fig. 9.

The impact modulus was calculated from the formula shown below, developed by Dr. L. B. Tuckerman, of this Bureau.

Factory Number	Style of Glass	Number of Pieces Tested	Average Modulus ² of Rupture	Average Variation from Mean Modulus	Per Cent Variation from Mean Modulus	Average Modulus of Elasticity	Average Variation from Mean Elasticity	Per Cent Variation from Mean Elasticity	Average Deflection	Average Load	Maximum Thickness	Minimum Thickness	Average Thickness	Number of Pieces Tested	Actual Impact	Average Impact for One Inch Thickness	Maximum Thickness	Minimum Thickness	Average Thickness	Impact Modulus of Rupture
2	3/8" Rough Wire	25	5200	523	10.0	847×10 ⁴	67×10 ⁴	7.9	.068	60.20	.385	.358		25	.212	.551	.386	.369	.372	583
		24	5160	241	4.6	872×10 ⁴	41×10 ⁴	4.7	.066	59.00	.385	.368		25	.201	.498	.402	.362	.376	572
		25	5300	561	10.5	873×10 ⁴	48×10 ⁴	5.6	.073	59.80	.386	.365		24	.189	.508	.388	.362	.376	556
		25	5220	441	8.4	864×10 ⁴	52×10 ⁴	6.1	.069	59.66	.385	.364	.375	25	.201	.519	.392	.364	.374	570
2	1/4" Ribbed Wire (Brown)	78	6200	700	11.2	896×10 ⁴	71×10 ⁴	7.9	.109	37.80	.289	.251	.277	76	.184	.639	.290	.268	.280	646
		25	5220	266	5.1	954×10 ⁴	47×10 ⁴	4.9	.084	29.00	.273	.250		25	.138	.508	.279	.259	.268	588
		24	5480	503	9.2	955×10 ⁴	77×10 ⁴	8.0	.093	31.00	.277	.256		25	.145	.603	.275	.225	.246	630
		25	7320	879	11.8	1215×10 ⁴	85×10 ⁴	7.0	.104	31.80	.260	.226		24	.142	.620	.247	.228	.239	712
2	1/4" Ribbed Wire		6007	549	8.7	1041×10 ⁴	69×10 ⁴	6.6	.094	30.60	.270	.244	.253		.142	.612	.267	.237	.250	643
		24	5263	275	5.4	939×10 ⁴	40×10 ⁴	4.2	.076	42.20	.324	.293		26	.127	.415	.328	.295	.304	525
		24	5350	306	5.2	975×10 ⁴	23×10 ⁴	2.3	.080	40.20	.320	.289		24	.140	.449	.322	.290	.308	558
		24	5150	463	8.9	963×10 ⁴	41×10 ⁴	4.3	.077	42.60	.325	.296		25	.143	.495	.321	.293	.307	561
1	1/4" Ribbed Wire	25	5418	390	7.7	947×10 ⁴	44×10 ⁴	4.6	.083	45.00	.323	.288		15	.135	.453	.320	.298	.307	541
		25	5123	389	7.5	940×10 ⁴	59×10 ⁴	6.2	.079	41.00	.330	.290		22	.145	.465	.329	.301	.313	553
			5261	365	6.8	957×10 ⁴	41×10 ⁴	4.3	.079	42.20	.324	.291	.307		.138	.455	.324	.295	.308	548
		25	5660	729	11.1	879×10 ⁴	68×10 ⁴	7.7	.074	68.20	.394	.357		11	.247	.650	.388	.375	.382	626
2	3/8" Ribbed Wire	25	5950	853	14.3	874×10 ⁴	69×10 ⁴	7.8	.076	74.20	.409	.351		25	.255	.624	.398	.367	.384	639
		24	6430	809	12.5	831×10 ⁴	58×10 ⁴	7.0	.081	42.60	.392	.361		25	.281	.733	.392	.367	.384	654
			6013	797	13.3	861×10 ⁴	65×10 ⁴	7.5	.077	61.67	.398	.356	.381		.261	.669	.393	.369	.383	640
		25	5750	582	11.2	969×10 ⁴	52×10 ⁴	5.3	.069	64.60	.384	.354		24	.157	.435	.386	.351	.362	543
1	3/8" Ribbed Wire	24	5457	556	10.2	938×10 ⁴	72×10 ⁴	7.5	.071	61.40	.385	.351		25	.157	.433	.390	.351	.362	535
		15	5576	215	3.8	942×10 ⁴	59×10 ⁴	6.0	.070	65.80	.404	.346		25	.150	.429	.373	.349	.357	527
		25	5460	327	6.0	972×10 ⁴	54×10 ⁴	5.5	.071	63.80	.400	.351		25	.156	.423	.400	.344	.366	539
		25	5940	573	9.6	960×10 ⁴	58×10 ⁴	6.0	.075	66.60	.395	.343		25	.158	.432	.395	.351	.366	539
2	3/8" Corrugated Wire— 3/4" depth		5636	450	8.1	956×10 ⁴	59×10 ⁴	6.0	.071	64.46	.394	.349	.365		.156	.430	.389	.349	.363	537
		25	9700	1538	15.8	372×10 ⁴	45×10 ⁴	11.3	.043	120.60	.344	.317		25	.323	.974	.344	.317	.331	505
		25	10000	1260	10.2	373×10 ⁴	26×10 ⁴	7.0	.048	125.00	.348	.316		25	.309	.922	.354	.315	.334	490
		24	9100	1415	15.5	349×10 ⁴	33×10 ⁴	9.5	.041	107.00	.365	.323		20	.301	.932	.347	.320	.336	469
2	3/8" Corrugated Wire—1"d.— (Colored)		9600	1404	13.8	365×10 ⁴	35×10 ⁴	9.3	.044	117.53	.352	.319	.335		.311	.943	.348	.317	.334	488
		15	15450	1410	9.1	616×10 ⁴	59×10 ⁴	9.5	.044	154.20	.324	.303		24	.277	.879	.337	.304	.316	616
		22	17450	1555	8.5	622×10 ⁴	65×10 ⁴	10.4	.042	158.60	.339	.290		25	.303	.938	.333	.310	.322	641
		20	15100	1282	8.4	618×10 ⁴	51×10 ⁴	8.2	.037	167.80	.336	.296		24	.266	.856	.323	.292	.309	612
2	3/8" Corrugated Wire—1"d.		16000	1416	8.7	619×10 ⁴	58×10 ⁴	9.4	.041	160.20	.333	.296	.318		.282	.891	.331	.302	.316	623
		22	12980	1490	11.4	548×10 ⁴	24×10 ⁴	4.3	.040	150.60	.337	.320		24	.258	.798	.369	.319	.336	544
		24	14700	1420	10.6	635×10 ⁴	51×10 ⁴	8.0	.039	155.80	.323	.307		25	.269	.817	.355	.310	.331	602
		22	13350	1520	11.4	588×10 ⁴	52×10 ⁴	5.7	.037	154.20	.355	.311		25	.297	.903	.352	.316	.330	609
2	3/8" Aqueduct		13343	1480	11.1	587×10 ⁴	42×10 ⁴	7.0	.039	153.53	.338	.313	.327		.278	.849	.359	.315	.332	585
		75	4820	675	12.7	688×10 ⁴	42×10 ⁴	6.1	.087	48.52	.373	.323	.348	68	.194	.600	.358	.315	.342	524

$$S = 18 \frac{E}{AL} W$$

E = Young's modulus

A = Cross-sectional area of sample

L = Length of span

W = Work in ft. lbs. to obtain a break

S = Impact modulus in ft. lbs. per sq. in.

All shock effects are neglected in this computation and the calculations made as if the glass under impact were quasi-stationary.

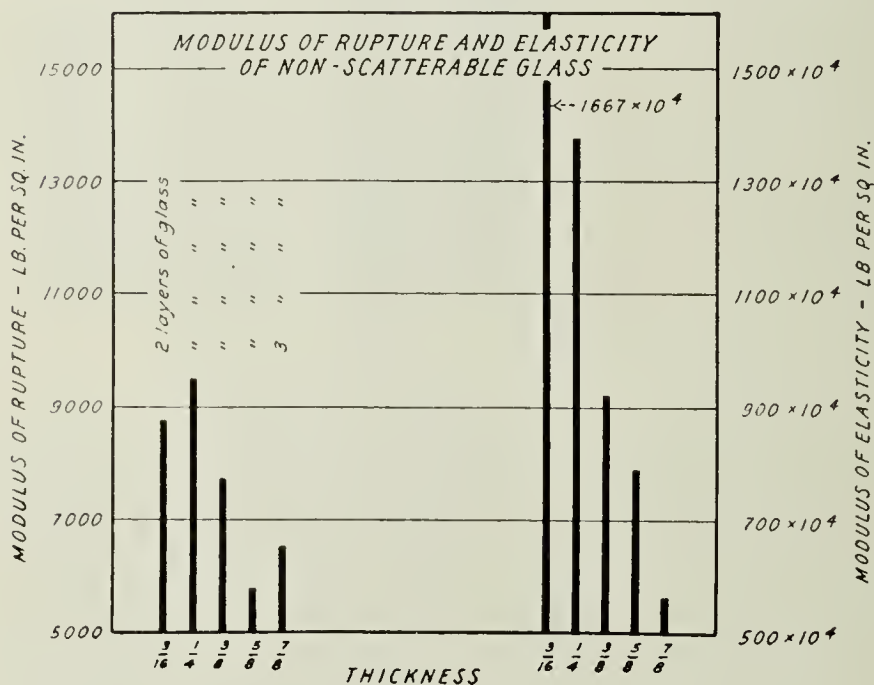


FIG. 6.

Stress strain diagrams for three thicknesses of window glass and a wire glass are shown on Figs. 10, 11, 12 and 13.

Brief Discussion of Results

Considering the type of material being tested and the fact that all samples contain a number of minute cracks and scratches, the uniformity of results seems to be quite good.

All samples have diamond-cut edges which are, therefore, probably fractured or chipped to a considerable extent. The polished glass might in addition contain considerable minute fractures under the polished surface.¹ All of these fractures tend to reduce the strength of the glass below the theoretical value which is probably considerably greater than any obtained. Breaking the glass with the diamond cut uppermost might give an increased strength over samples broken with the cut edges down, owing to the

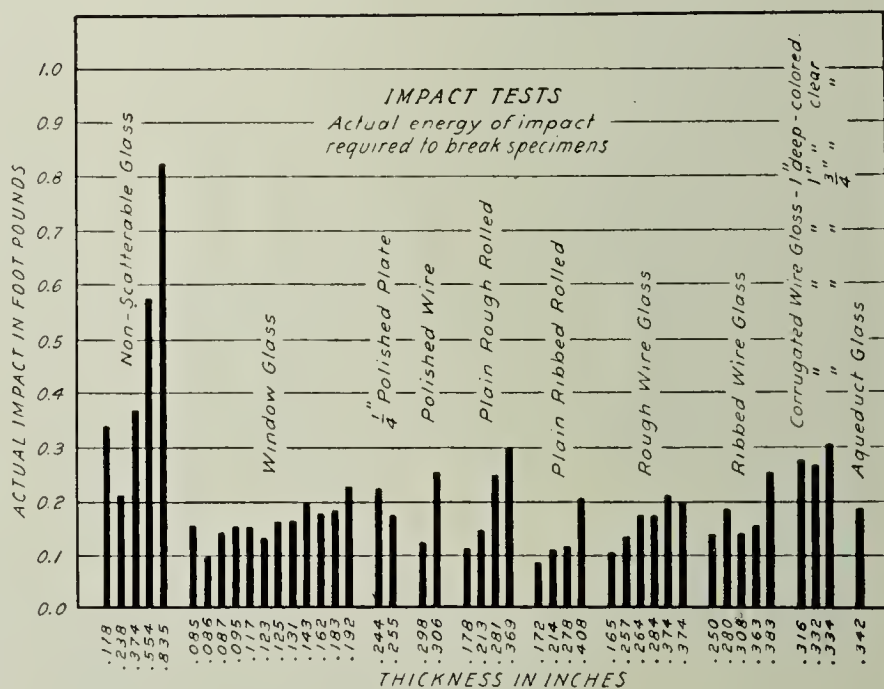


FIG. 7.

¹ "The Structure of Abraded Glass Surfaces," *Trans. Optical Soc.*, 23 [3], 141 (1921-22).

fact that the fractures are then put in compression rather than in tension. This factor was not considered in tests, however, except that where samples of clear sheet glass showed some bow the sample was tested with the convex side of the bow down, so that the diamond cut is always on the same side, i. e., the upper side in this case.

All processed glass was tested with processed side up, which is the position of greatest strength under the conditions of the test. The results indicate that the strength of the glass has not been reduced to any extent when tested in such a position.

The following Table II, shows the maximum and minimum values for modulus of rupture obtained from any single group of samples of various types of glass:

TABLE II

LIMITING VALUES OBTAINED FOR MODULUS OF RUPTURE IN LBS. PER SQ. IN.		
Rolled Figured Sheet	Plain Rough Rolled Glass	8625- 5500
	Ribbed Rolled Glass	5714- 4671
Wire Glass	Plain Rough Wire Glass	7900- 5640
	Ribbed Rolled Wire Glass	7320- 5220
	Corrugated Wire Glass (1" deep)	17450-12980
	Corrugated Wire Glass (3/4" deep)	10000- 9100
	Polished Wire Glass	7470- 5569
Polished Plate Glass		6997- 6027
Special Nonscatterable Glass		9500- 5750
Clear Sheet Glass (Window Glass)		12775- 6111

The following values for modulus of rupture may be considered as safe working strength for various types of glass.

	Lbs. per sq. in.
Single strength or double strength window glass and 26 oz. clear sheet glass	7000
29 oz.-34 oz. and 39 oz. or 3/16" clear sheet glass and 1/4" plate	6500
Rolled sheet and wire glass	6500
Ribbed rolled sheet or wire glass	5300
Corrugated wire (1" deep)	13500
Corrugated wire (3/4" deep)	9500



FIG. 8.

VALUES FOR YOUNGS' MODULUS FOR VARIOUS TYPES OF GLASS

	Lbs. per sq. in.
Single and double strength window glass	11,000,000
26 oz., 29 oz., 34 oz., 39 oz. clear sheet glass	10,500,000
Polished plate glass	10,000,000
Rough rolled glass	9,700,000
Nonscatterable glass—varies greatly with thickness	$\left\{ \begin{array}{l} 3/16'' \\ 7/8'' \end{array} \right.$ 16,670,000
	5,500,000

Comparing clear sheet glass with polished plate or rough rolled plate glass, the former is somewhat the stronger. Ribbed glass gives a low value, but that may be explained in part because the thickness used in

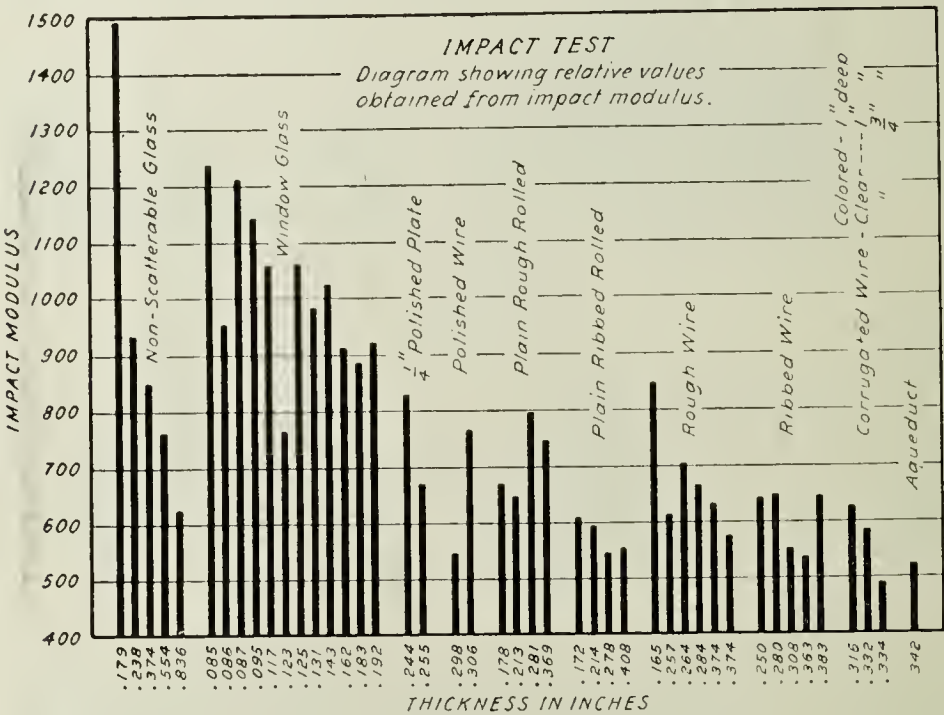


FIG. 9.

the calculations was taken to the top of the rib rather than at the base or an intermediate point between. As the glass is sold on a basis of thickness measured to that point the strength is relative.

Generally speaking, thin glass shows greater strength per unit thickness than thick glass both under

slow loading and under impact. Figures 1, 2, 6 and 9 will show this fact. The rather high strength developed by the corrugated glass under slow loading as compared to its strength under impact is also worthy of notice. Tests to determine the strength of glass in frames are now being made both with respect to its resistance to impact, to slow loading in the center and to uniform loading over the entire area. Results of these tests will be published at a later date.

The values obtained for modulus of elasticity also decrease with the thickness of the glass rather consistently, this fact being especially noticeable in the laminated nonscatterable glass.

Stress strain relations indicate a truly elastic body, all curves obtained being practically straight lines. Experiments were also tried to show whether or not the glass returned to its original position when the load was removed. Load was applied, then removed, then an increased load applied and removed up to the breaking point, the samples in all cases returning to their original position. Long continued loading might have deformed the samples as might be expected of plastic or viscous substance,

but the glass exhibits all the properties of a solid within the time limits of the tests.

The results obtained from impact tests do not show the same rate of increase in strength with increase in thickness as is shown for breaks ob-

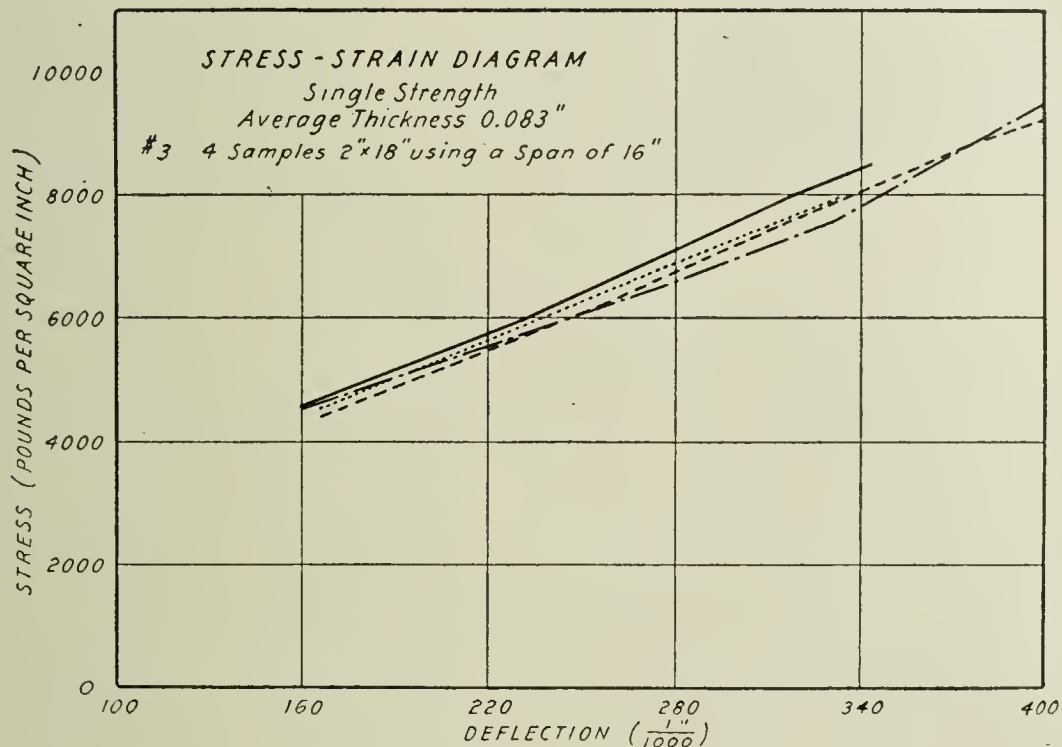


FIG. 10.

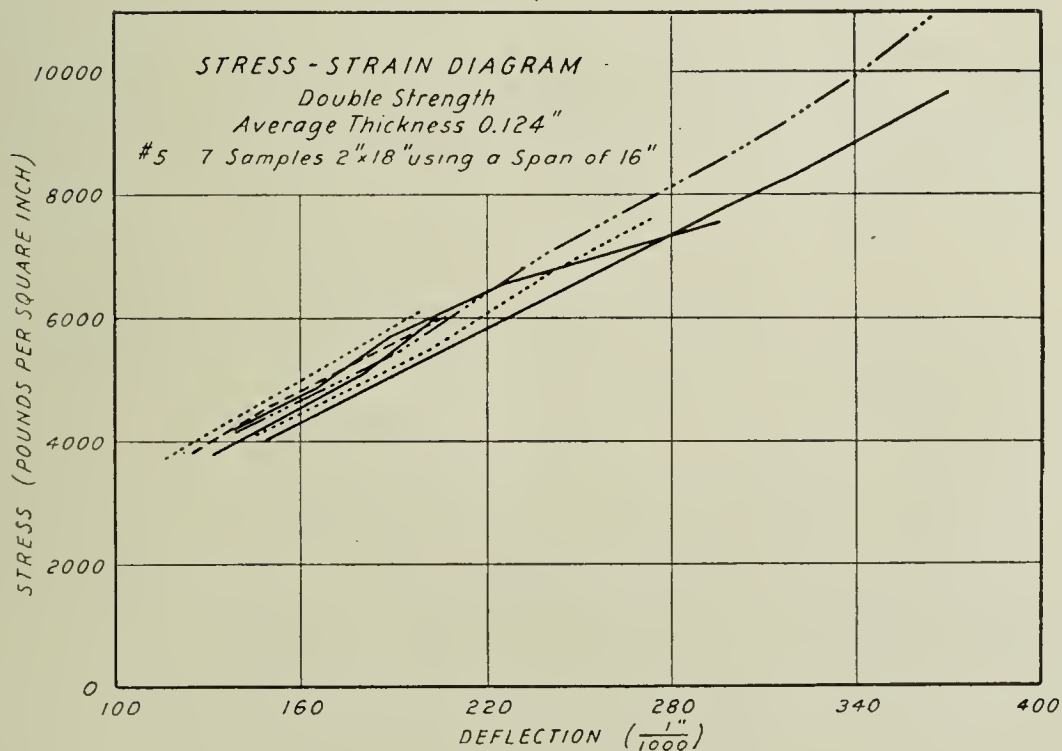


FIG. 11.

tained by slow loading. That is, the load required for a break increases approximately as the square of the thickness, whereas the impact required for a break increases in about a direct proportion to the thickness.

Experiments indicated that uniform results in terms of energy could not be obtained if different sized hammers were used, striking at different

velocities to produce a break. Heavier hammers at lower velocities broke the glass with less energy than light hammers with high velocity. This indicates that results are probably not theoretically comparable, as the same hammer striking at different velocities was the way in which the results were obtained. Geometrically proportional samples broken

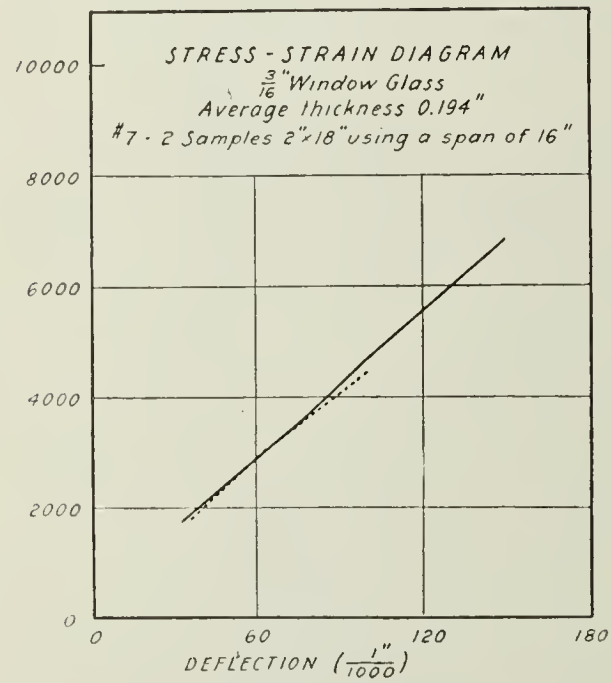


FIG. 12.

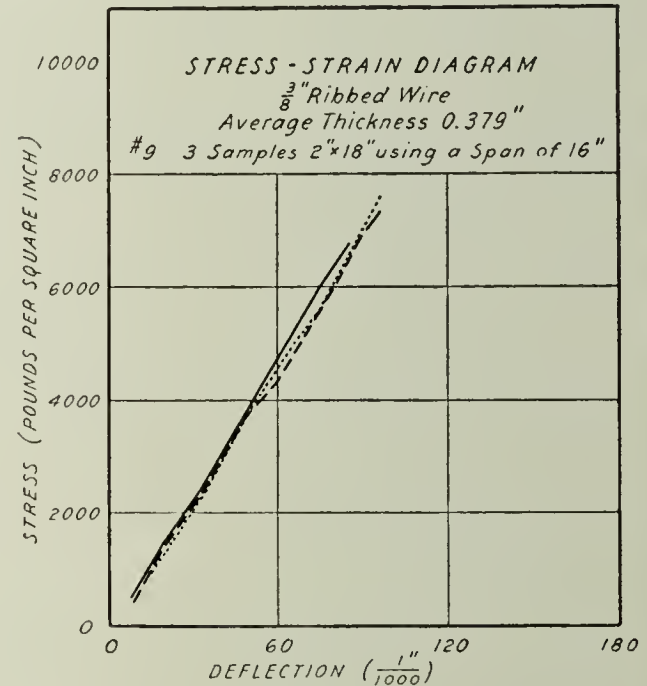


FIG. 13.

with hammers varying in size, so that a uniform velocity of blow would be obtained for breaking each sample, would probably give values more nearly approaching the true strength of the glass. Such a method of testing would hardly be practical, as a simple method of testing glass.

BUREAU OF STANDARDS
WASHINGTON, D. C.

EFFECT OF HYDROGEN ION CONCENTRATION UPON CLAY SUSPENSIONS¹

BY F. P. HALL

ABSTRACT

This paper includes a preliminary report on the study of clay suspensions. Two methods commonly used for measuring the hydrogen and hydroxyl ion concentrations of aqueous solution are outlined. The hydrogen ion concentration of the water extract from several clays is given. The effect of the hydrogen ion concentration of the suspending medium on the rate of settling of suspended clay is given for several different clays. The action of alkali on suspended clay is studied.

Introduction

The effect of electrolytes on stabilizing and precipitating clay suspensions has long been studied. In general it may be deduced from previous researches that the hydrogen ion is a flocculator and the hydroxyl ion a deflocculator of clay suspensions. A great deal of work² has been done on the study of the amount of electrolyte required to flocculate and deflocculate clay suspensions, but very little work has been done to determine the hydrogen ion concentration that the required amount of electrolyte will produce in the solution. It is the object of this investigation to study the hydrogen ion concentration or degree of acidity of various clay suspensions with varying amounts of electrolytes and attempt to correlate these facts with any known properties of the clays. While this paper deals only with the effect of hydrogen and hydroxyl ion concentration on clay suspensions, we realize that other ions have a marked effect on the rate of settling of suspensions. The valence of the ion is a very important factor. However, the case is simplified by considering only univalent ions, H^+ and OH^- .

A careful distinction must be drawn between the amount of acid or total acid concentration and the hydrogen ion concentration or degree of acidity. The distinction is just as important as in the parallel case of quantity of heat and degree of heat or temperature. Solutions of .01 *N* hydrochloric acid and .01 *N* acetic acid contain equivalent amounts or concentrations of acids, as determined by titration with standard alkali (to appropriate end points), but the hydrogen ion concentration in the case of the strong acid (HCl) will be about .01 *N* while the hydrogen ion concentration in the case of the weak acid (acetic acid) will be about 0.0004 *N*.

Various methods are used to express the hydrogen ion concentration, illustrated by the following examples, all of which indicate the same concentration of hydrogen ions.

¹ Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce. Recd. May 17, 1923.

² Bureau of Standards, *Tech. Paper*, No. 23.

- (1) $\frac{1}{100,000} N$
- (2) $.00001 N$
- (3) $1 \times 10^{-5} N$
- (4) pH 5.0

The fourth method proposed by Sørensen and often called the Sørensen value or the pH value is used throughout this article. The expression "pH" involves the logarithm of the reciprocal of the hydrogen ion concentration ($\text{pH} = \log 1/H^+$). The dissociation constant of water at 25°C is about 10^{-14} and since in pure water $H^+ = OH^-$ then the pH value of pure water is 7.0. As compared with water, a solution with a pH value less than 7 is acid while one greater than 7 is alkaline.

Methods of Measurement of the Hydrogen Ion Concentration of Aqueous Solutions

The two principal methods of measuring the hydrogen ion concentration are (1) by the use of the hydrogen electrode and (2) a colorimetric method involving the use of dyes or indicators whose constants have been determined by the use of the hydrogen electrode. Methods for using the hydrogen electrode are described fully by W. M. Clark.¹ The apparatus recommended by Clark was used in this work and consisted of a Clark hydrogen electrode outfit—1, Leeds and Northrup type K. potentiometer and galvanometer. A tenth normal calomel electrode was used with a connecting cell filled with saturated potassium chloride. The Bjerrum extrapolation was not made.

The colorimetric method devised by L. J. Gillespie² was employed only when clear solutions were to be examined, because any appreciable amount of clay adsorbs the color reagent and vitiates the results. In the case of unbuffered solutions it is best to use the indicators if possible. Both the indicators and the hydrogen electrode were checked against standard buffer solutions before each series of solutions was examined. By buffer action we mean the resistance exhibited by a solution to change in pH through the addition or loss of acid or alkali. The buffer action of a solution is dependent upon the character and concentration of the constituents. Weak acids and bases in the presence of their salts exhibit buffer action which is greatest in concentrated solutions. O. Arrhenius³ has shown that soils possess buffer action. Some soils exhibit it to a greater extent than others. This buffer action in soils is probably due to the presence of organic acids.

¹ "The Determination of Hydrogen Ions," by W. M. Clark, Williams and Wilkins Co., Baltimore, 1922.

² "Colorimetric Determination of the Hydrogen Ion Concentration without Buffer Solutions, with Special Reference to Soils," *Soil Science*, 9 [2], 115 (1920).

³ O. Arrhenius, "The Potential Acidity of Soils," *Soil Science*, 1922.

The Hydrogen Ion Concentration of the Water Extract from Several Clays

Table I gives the results of the examination of the water extracts from a number of clays. As the pH value¹ is dependent on the relative amounts of clay and water present, the ratio of water to clay was the same in every test except one. This ratio of water to clay denoted as *w/c* was 4. The values given are those obtained with the hydrogen electrode but they were checked by the colorimetric method. In general the colorimetric method gave higher results from .1 to .2 in pH value.

TABLE I
THE pH VALUE OF THE WATER EXTRACT FROM SEVERAL CLAYS

$\frac{w}{c} = \frac{4}{1}$

Clay	pH	Clay	pH
Kaolins and shales		Ball Clays	
South Carolina kaolin.....	4.40	Lk. Knowles No. 1.....	4.15
English china.....	5.20	Lk. Knowles No. 2.....	4.50
English china.....	5.45	Lk. Knowles No. 12.....	5.95
Bentonite.....	9.72 ^a	Whitway ball clay.....	4.40
N. Carolina kaolin.....	4.75	P. M. C. Co. ball clay 90.....	5.65
Delaware kaolin.....	5.10	Pooles Pike.....	5.25
Virginia kaolin.....	5.05	Superior B. C.....	3.80
Penna. clay.....	5.75	Blue ball clay.....	3.65
Fla. kaolin.....	5.90	J. P. T. B. No. 11.....	5.65
Ga. kaolin.....	4.15	Dorset E. B.....	4.10
Shale (N. W. T. C. Co.).....	6.70	Cooley.....	5.00
Hyd. P. B. Co. clay.....	7.27	M. & M. No. 11.....	3.85
Fallston fire clay.....	8.40	Fayles.....	3.90
Cutters No. 2.....	2.95	Grindley.....	5.75
H. & W. fire clay.....	5.00	M. & M. No. 18.....	5.70
Stoneware grog.....	6.10	J. P. Tenn. B. No. 10.....	5.55
Met. Pav. shale.....	6.30	J. P. Tenn. B. No. 9.....	5.50
Crossly No. 1.....	3.70	English ball.....	4.65
Colorado clay.....	3.10	Tenn. ball No. 3.....	3.20
Fla. kaolin.....	6.80	Ky. ball No. 4.....	5.20
		German clay.....	3.85

^a $\frac{w}{c} = \frac{350}{5}$

Values given to nearest .05.

An examination of the results presented shows that the pH value of the extracts examined varies from 3 to 8.5. The ball clays in general give no stronger acid extracts than the kaolins. There does not seem to be any generalization that can be made in this respect.

A great deal of acidity of the extract is due to the soluble salts present

¹ This has been illustrated in an article by R. M. Salter and M. F. Morgan, entitled, "Factors Affecting Soil Reaction," which was published in the *Journal of Physical Chemistry*, 27, 117 (1923).

but just how much cannot be said because of the difficulty of removing adsorbed salts. Table II shows the result of washing out part of the salt. Two hundred grams of water were mixed with 50 grams of clay and the pH of this extract was determined. Then the water was decanted off

TABLE II
EFFECT OF WASHING SOLUBLE SALTS OUT OF CLAY

Clay (pH)	$\frac{w}{c} = \frac{4}{1}$	1st extract	3rd extract	6th extract	9th extract	12th extract
South Carolina kaolin.....		4.40	4.70		4.70	4.75
Ga. kaolin.....		4.15	4.25	4.80	4.70	4.75
Tenn. ball No. 3.....		3.20	3.40	3.65	3.70	3.80
English china.....		5.45	5.65	5.75	5.80	6.15
Fallston fire clay.....		8.40	8.15	8.05	7.80	7.20

Effect of Aging of Clay on pH of Water Extract

Clay	$\frac{w}{c} = \frac{4}{1}$	Initial	after 53 days	after 130 days
German ball.....		3.85	4.20	4.20
Ky. ball No. 4.....		5.20	5.05	4.80
			After 7 months	After 2 years
Clay mixture X.....			4.12	3.78

(the clays examined were flocculated at this pH) and another 200 grams of water added and this procedure was repeated twelve times. In general a clay that gives an acid extract with the first addition of water will decrease in acidity as successive amounts of water are added. Clays giving an alkaline extract will usually decrease in alkalinity as they are washed.

Table II also shows the results of tests carried out on clays that have aged. The clays were thoroughly pugged and then stored in a damp atmosphere. Samples of the clays were taken from time to time and the pH value of the water extract determined. G. A. Bole¹ suggests that the increased plasticity of clays caused by aging might be due to increase of hydrogen ions. The change in the latter is only slight as is shown in the Table. In two cases there is an increase in hydrogen ions and in another a decrease. From the small amount of data obtained it would be impossible to say whether or not aging increases the hydrogen ion concentration of the clay-water mixture. It is possible that the aging causes a hydration of the gel colloid and this in turn increases plasticity.

The Rate of Settling of a Clay Suspension as a Function of the Hydrogen Ion Concentration of the Suspending Medium

In order to obtain results that can be duplicated in the study of the rate of settling of suspensions it was found to be necessary to follow exactly the same procedure in making up all of the suspensions. The temperature

¹ Mechanism of the Plasticity of Clays, *Jour. Amer. Ceramic Soc.*, 5, 469 (1922).

of the suspension must be closely controlled and the order of addition of clay and electrolyte to the water must be the same in every case. The same is true of the time of agitation of the suspension. In the present investigation the suspensions were made in graduated glass cylinders and the time required for the material to settle a certain distance was determined. From this data the average rate of settling was calculated. Each curve shown in Figs. 1 and 2 shows a maximum and a minimum rate. The point at which the material shows a maximum rate of settling is commonly called the iso-electric point while that at which it shows a minimum is called the point of maximum degree of deflocculation. The time that a clay will remain suspended depends to a great extent on the time that the suspension is agitated. For instance, if a clay suspension at about the point of maximum deflocculation is agitated for a day, a part of the clay will remain suspended indefinitely.

O. Arrhenius¹ obtained curves very similar to those shown in Figs. 1 and 2 but he shows that the iso-electric point of a clay suspension is very sharp. This we did not find to be true in the case of the clays that were examined. Arrhenius examined two clays and found the iso-electric point of the two clays to be at the same pH. We found that the iso-electric point of the several clays was not exactly at the same pH but lies between pH 2.7–4.0, depending on the character of the clay. The point of maximum deflocculation varies from pH 11–12. Neither of these points is very sharp and both vary with the ratio w/c .

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¹ Olof Arrhenius, "Clay as an Ampholyte," *Jour. Amer. Chem. Soc.*, **44**, 521 (1922).

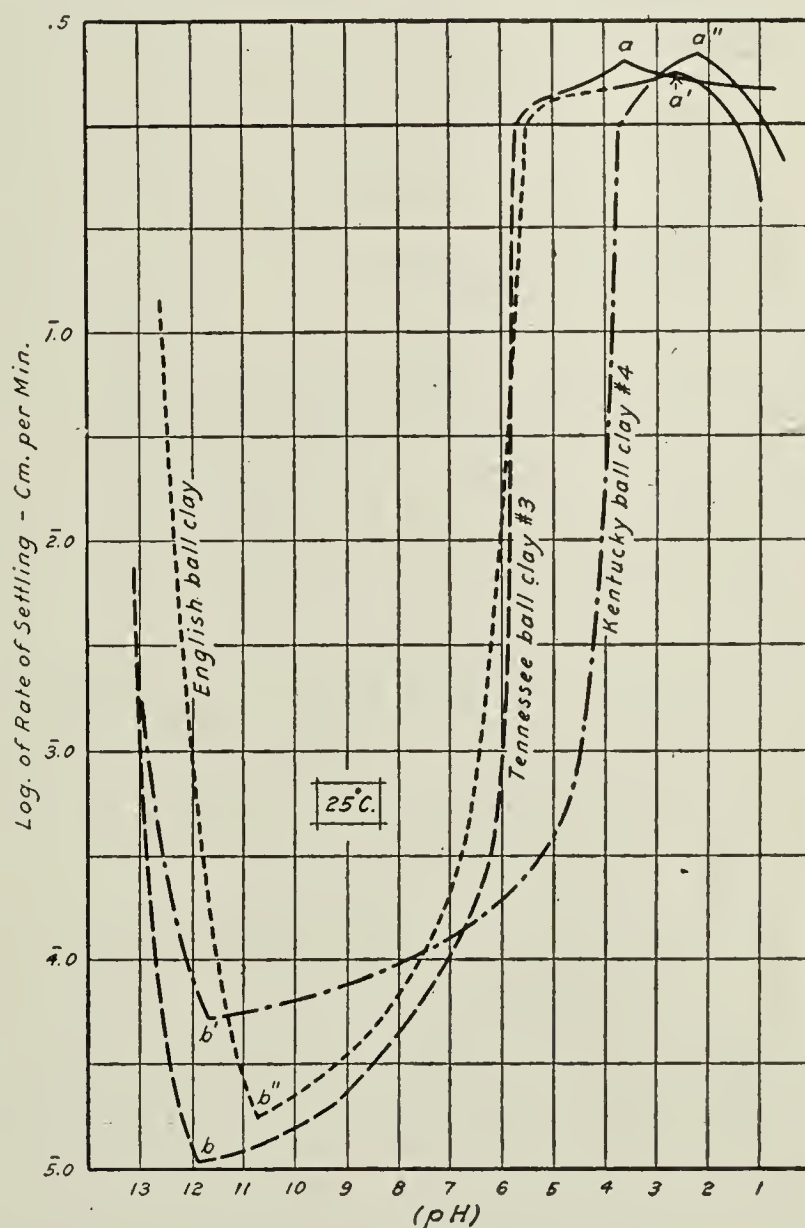


FIG. 1.—Showing the relation between the rate of settling of three ball clays and the pH value of the suspending medium. The full lines indicate the average rate of settling of the flocculated clay and the broken lines indicate the rate of settling of the finest particles over the deflocculated range. Points a , a' , a'' , are the iso-electric points while b , b' , b'' , are the points of maximum deflocculation. The electrolytes used were sodium hydroxide and hydrochloric acid.

This failure to find a sharp iso-electric¹ point is probably due to the fact that clays contain a mixture of colloids such as silica, alumina, etc. If we were dealing with one colloid rather than a mixture we would expect

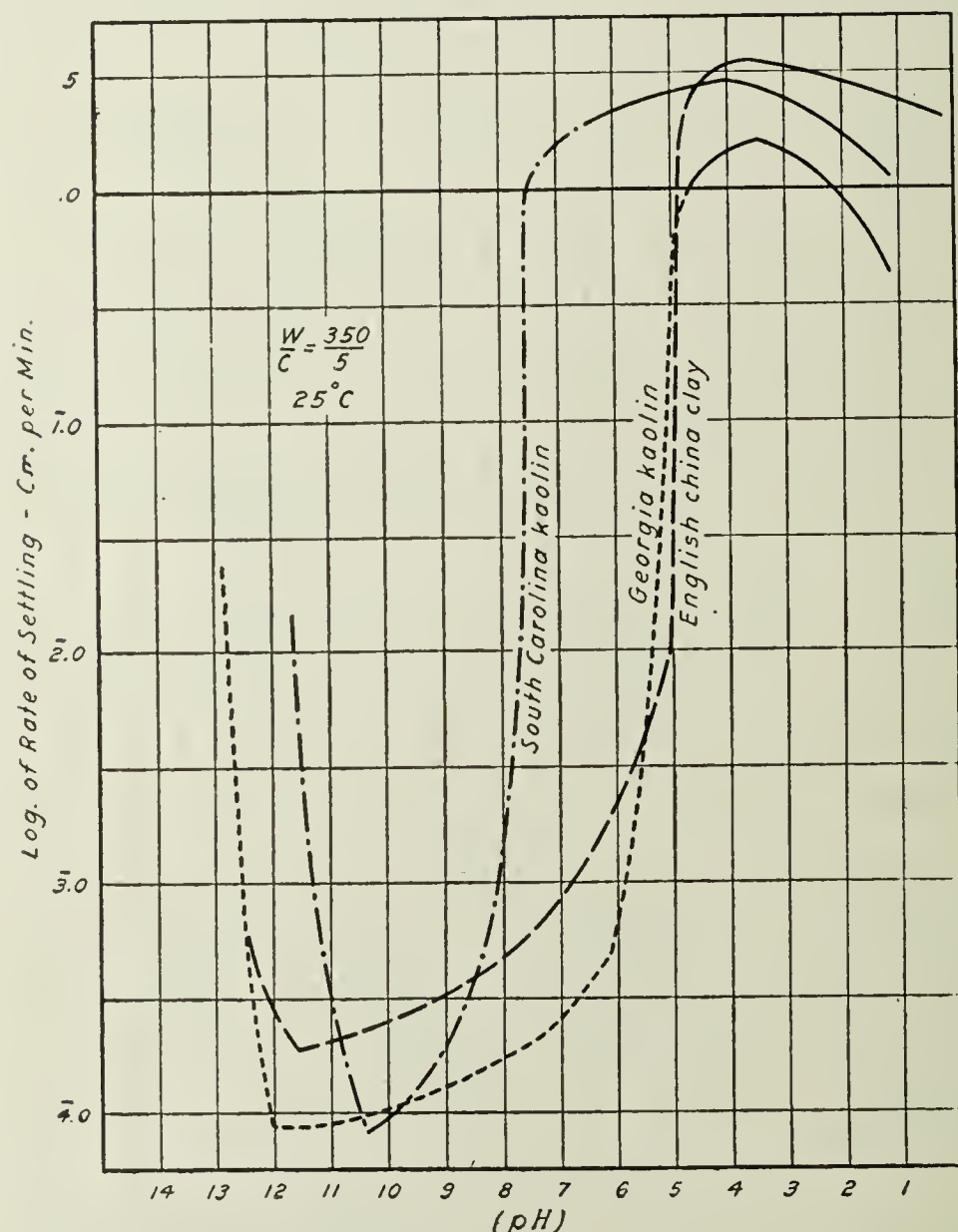


FIG. 2.—Showing the relation between the rate of settling of three kaolins and the pH value of the suspending medium. The full lines indicate the average rate of settling of the flocculated clay and the broken lines indicate the rate of settling of the finest particles over the deflocculated range.

to find a sharp iso-electric point. In Table III the iso-electric points and points of maximum deflocculation are tabulated for several clays.

The Action of Alkali and Acid on Suspended Clays²

If a quantity of alkali is added to water the pH value of the water is increased and if the same quantity of alkali is added to the same volume of a clay suspension the pH is increased but not as much as with water alone, due to the action of the alkali on the clay. This is shown in Fig. 4 in the case of the Florida kaolin. Here the heavy line denotes the effect of the addition of 0.1 N sodium hy-

¹ A. W. Thomas and M. W. Kelly, *Jour. Amer. Chem. Soc.*, **44**, 206 (1922), do not obtain a sharp iso-electric for collagen and conclude that collagen is a mixture rather than one simple protein.

² Geller and Caldwell (*Jour. Amer. Ceram. Soc.*, **4** [6], 479 (1921) made a study of the action of alkali on clay. They found that alkali was adsorbed by the clay. Their method of examination was different from that outlined in this article. They attempted to titrate the alkali that did not react with the clay by centrifuging the suspension and separating the clay from the alkaline solution. They were not able to separate all of the colloidal matter from the suspending medium. Therefore, when they titrated the solution containing suspended matter they disturbed the adsorption equilibrium and did not determine the actual amount of alkali adsorbed. This accounts for the difference between the two constants K and $1/n$ as determined by them and as given in Table V of this paper.

TABLE III
TABULATION OF PH VALUES OF CLAY SUSPENSIONS

$\frac{w}{c} = \frac{350 \text{ cc.}}{5 \text{ grams}}$

Clay	pH of water extract	pH at iso-electric pt.	pH at point of maximum deflocculation
English ball.....	5.50	2.78	10.96
Tenn. ball No. 3.....	3.80	3.63	12.01
Ky. ball No. 4.....	5.50	2.28	11.97
English china.....	5.80	3.63	11.60
Ga. kaolin.....	4.70	3.42	12.00
S. Carolina kaolin.....	4.80	3.99	10.32

TABLE IV
RATE OF ACTION OF ALKALI ON CLAY
Value of pH of Solution at Certain Intervals

Clay	6 hours	1 day	2 days	3 days
Fla. kaolin.....	9.43	9.39	9.39	9.38
Fla. kaolin.....	10.78	10.70	10.70	10.68
Fla. kaolin.....	11.37	11.30	11.29	11.28
Fla. kaolin.....	11.65	11.52	11.52	11.51

dioxide to 350 cc. of conductivity water. Under similar conditions acids also react with the clays as is shown in Fig. 3. The procedure in obtaining the data given in Figs. 3 and 4 was as follows: the electrolyte was added to the water, next the clay was added and then the solution was agitated and placed in a bath at 25°C. After 24 hours the pH value of the suspension was determined. The solution was further agitated and the pH again determined after an additional 24 hours. From the data shown in Table IV it is evident that the action was practically complete in 24 hours. This was true of all the clays except bentonite which required three days to reach equilibrium. From the amount of alkali added to a suspension and the pH value of the suspending medium at equilibrium it is possible to calculate the amount of alkali that has been taken out of solution by the clay.

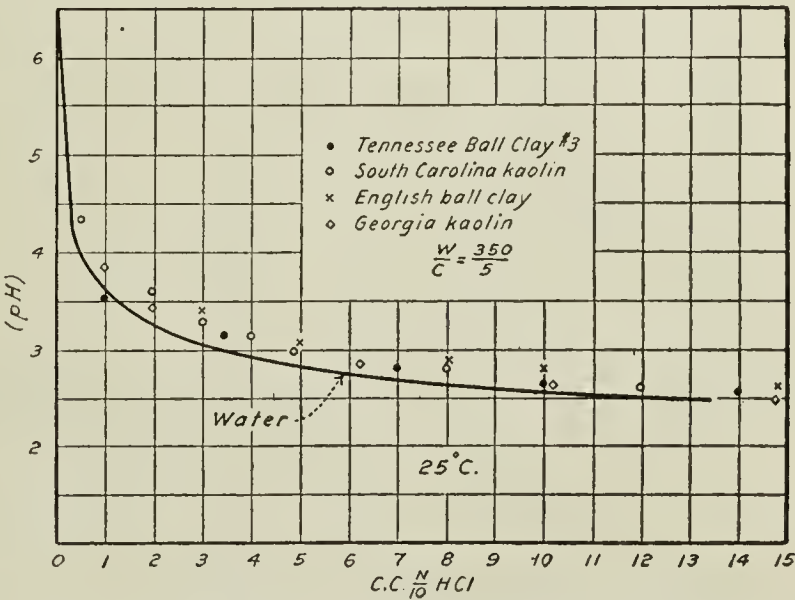


FIG. 3.—Showing that acids are absorbed by clays. In this paper the term “absorption” is used to designate the removal from solution of a dissolved substance, by a solid, regardless of the mechanism by which it occurs. “Adsorption” is considered as a special form of absorption, characterized by the accumulation of the dissolved substance upon the surface of the solid.

There are three ways by which this alkali could be removed from solu-

tion by the clay: chemical action, physical adsorption, and solid solutions. There is still a great deal of controversy concerning methods of distinguishing between these several actions, especially when one of the phases is in

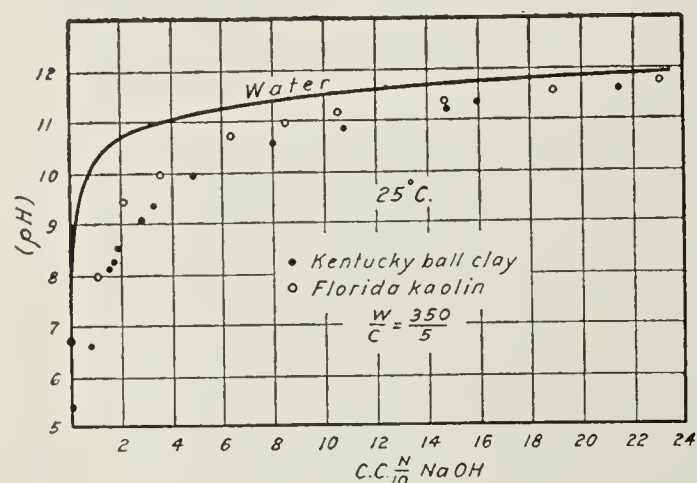


FIG. 4.—Showing that part of the alkali is removed from the solution by the suspended clay.

an extremely subdivided state. It is probable that there is no hard and fast distinction between these actions when dealing with substances in the colloidal state, that is to say, there is probably an overlapping of these actions and it is very difficult to say whether a certain action is purely physical adsorption or chemical action, or both. However, in presenting data concerning actions of this type it is well for the investigator to give his interpretation of his results. Sometimes this interpretation is not

agreeable to all, which is often due to a question of definitions.

When dealing with systems of this nature (clay-water-electrolyte) where the surface of the solid phase is very great, it is reasonable to expect that a great part of the electrolyte that is removed from solution is adsorbed on the surface of the solid phase. An equation has been used by Freundlich and others connecting the quantity of material adsorbed and the quantity of adsorbent. This equation is

$$\frac{x}{m} = KC\frac{1}{n}$$

where x is the amount of material in grams adsorbed by m grams of the solid adsorbing agent, C is the concentration in the solution after adsorption,

i. e., the equilibrium concentration, and K and n (where $n > 1$) are constants for a given solute and adsorbent. In this consideration the adsorbent is clay and the solute is sodium hydroxide. K is the amount of solute adsorbed when the concentration is unity. This should be proportional to the amount of surface of the solid phase. The amount

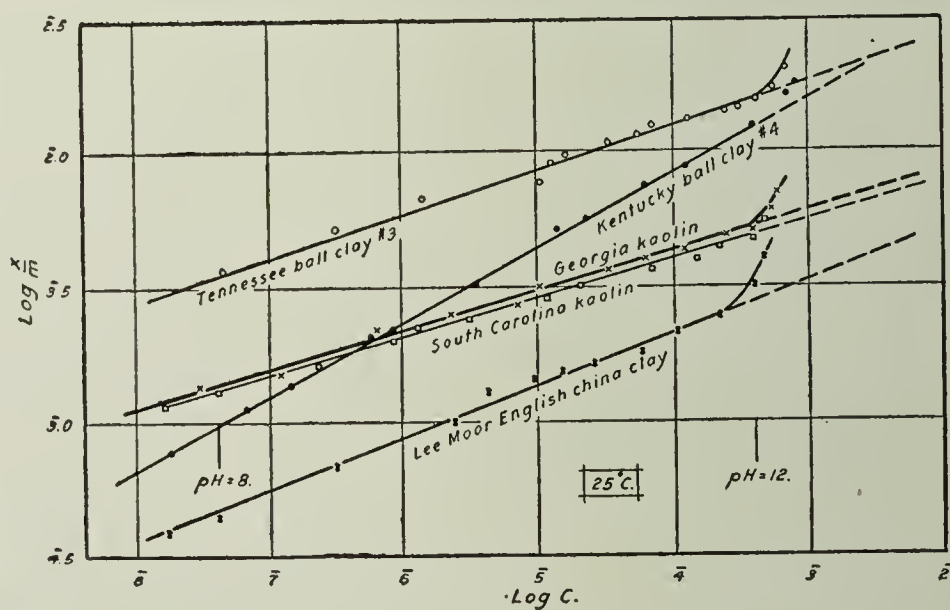


FIG. 5.—Illustrating an approximate straight line relation between $\log C$ and $\log x/m$ over a range of concentration between pH 7 and 12.

of surface exposed is dependent on the degree of subdivision of the solid phase. In fact the value of K should be an index of the degree of subdivision. The value of $1/n$ is the rate of change of $\log x/m$ with $\log C$. In cases of purely physical adsorption the value of $\log x/m$ should be

a straight line function of $\log C$. If $\log x/m$ is not a straight line function of $\log C$ and the curve passes through a maximum, this is an indication of chemical action. The results of plotting the values of $\log x/m$ against $\log C$ for a number of experiments are shown in Figs. 5 and 6. It is evident that there is a straight line

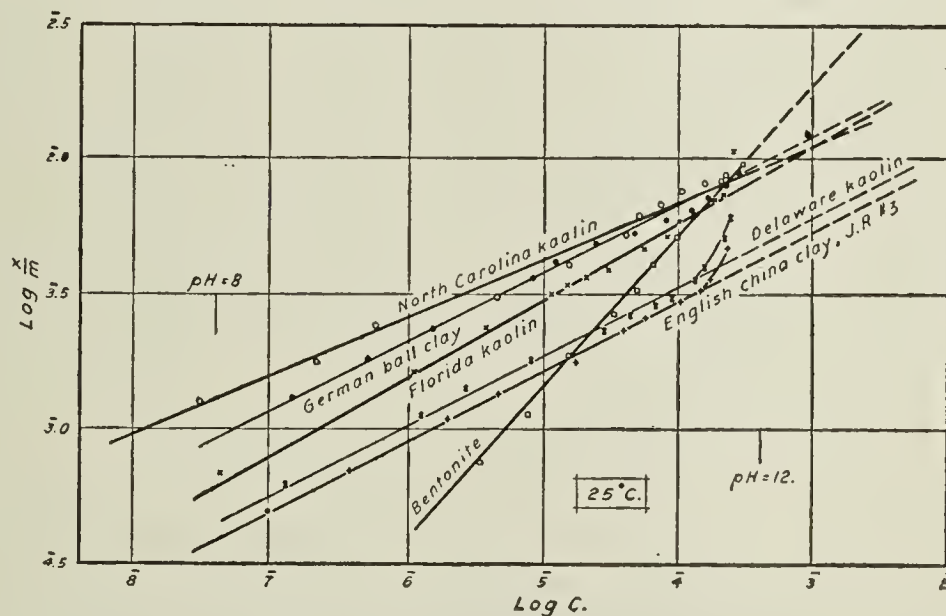


FIG. 6.—Illustrating an approximate straight line relation between $\log C$ and $\log x/m$ over a range of concentration between pH 7 and 12.

log relation between x/m and $\log C$, between pH 7 and 12. It is probable that between these values of concentration that the action of alkali on clay is primarily due to physical adsorption. However, at concentrations of alkali greater than pH 12 (pOH 2) it seems likely that

chemical action plays an important rôle. This is also illustrated in Fig. 7 where at concentrations greater than approximately pH 12 (pOH 2) the percentage of sodium hydroxide taken out of solution by the clay increases.

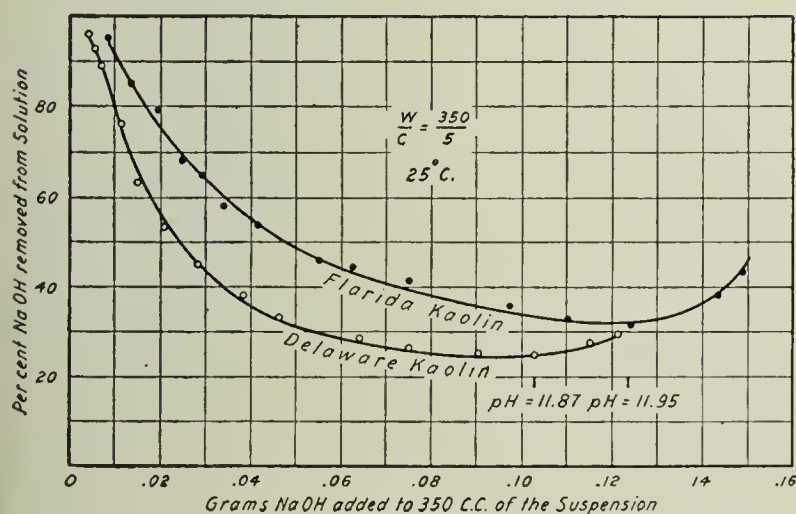


FIG. 7.—Showing that the percentage of alkali reacting with clay decreases with increase in concentration of alkali until a concentration of approximately pH 12 is reached. In concentration greater than pH 12 the reverse is true.

value of K as determined is affected by the presence of adsorbed salts that were originally in the clays. It is probable that the first small quantities of alkali are taken out of solution by the adsorbed salts, that is, by chemical reaction.

The values of the constants K and n are tabulated in Table V. If K is a correct index of the degree of fineness of the clay the arrangement shown in Table V is a classification of the clays according to degree of fineness.

It is highly probable that the

TABLE V
TABULATION OF CLAYS IN ORDER OF DESCENDING VALUE OF K

Clay	K	1/n	n
1. Bentonite.....	.89	.58	1.72
2. Kentucky ball clay No. 4.....	.107	.27	3.70
3. Florida kaolin.....	.089	.33	3.03
4. German ball clay.....	.080	.29	3.45
5. Tenn. ball clay No. 3.....	.056	.16	6.26
6. North Carolina kaolin.....	.047	.21	4.75
7. Delaware kaolin.....	.036	.26	3.85
8. English china J. R. No. 3.....	.032	.26	3.85
9. Georgia kaolin.....	.017	.15	6.70
10. S. Carolina kaolin.....	.015	.14	7.15
11. Lee Moor English china.....	.012	.19	5.25

Summary

1. No generalizations can be based upon the examination of the pH of the water extracts from a number of clays. That is, all ball clays do not give a more acid extract than all kaolins and *vice versa*.

2. For every clay-water-electrolyte mixture there exists a certain pH

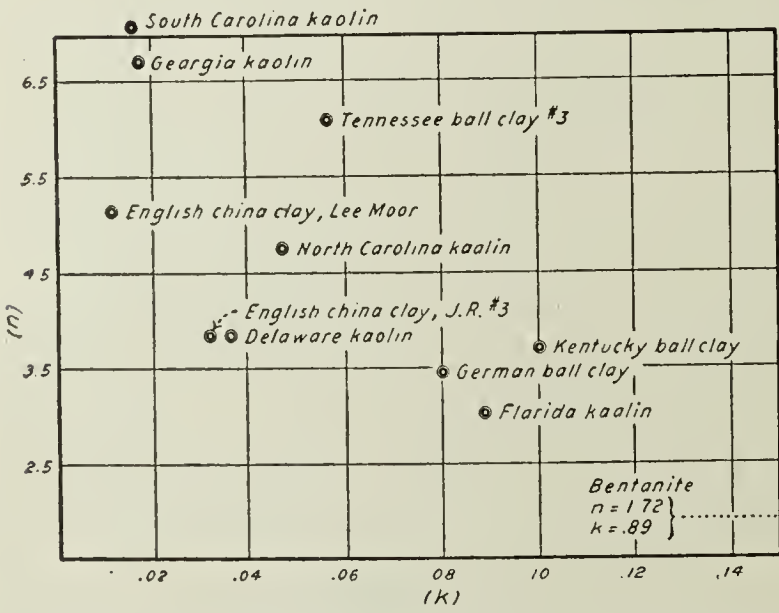


FIG. 8—The value of K and n as determined for a number of clays when the material adsorbed is sodium hydroxide.

(the iso-electric point) at which the rate of settling of the clay is a maximum and a pH at which the rate is a minimum (the point of maximum deflocculation). Neither of these points is very sharp. This may be due to the fact that we are dealing with a mixture of colloids and not with a single colloid. It is evident that a knowledge of these two points (iso-electric point and point of maximum deflocculation) would be advantageous in a number of processes, namely: purification

of clay, purification of water¹ and casting of clay bodies.

3. The action of alkali on clay over the range pH 7–12 can be explained

¹ An article on this subject appeared, at about the time this manuscript was completed, in the *Journal of the American Water Works Association*, 10, May, 1923, entitled, "The Use of Acid with Alum in Water Purification and the Importance of Hydrogen Ion Concentration," by J. R. Bayliss.

Another article on this subject is, "An Experimental Study of the Relation of Hydrogen Ion Concentration to the Formation of Flocc in Alum Solutions," *Public Health Reports*, 38, 5, 181, by Emery J. Therrault and W. M. Clark.

in certain cases as due primarily to adsorption. Above pH 12 the action seems to be primarily chemical rather than physical.

4. The value of K (one of the constants of the adsorption equation) as determined for a number of clays, might be used as a rough index of the degree of fineness of the clay. It is evident that the value of K could not be used as an exact index of the degree of fineness of the material because if we consider two solid phases with equal surfaces the activity of the two substances toward a given material is seldom the same. The adsorption of any substance by a solid is a function of the specific surface of the solid and is also dependent on the activity of the substance towards the material that is adsorbed.

Appendix¹

S. E. Mattson² has published some interesting results on the study of flocculation and deflocculation of clay suspensions. He studied the velocity of migration of clay and quartz particles suspended in water, under a drop of electrical potential. As the charge in the particle increases, the velocity of migration increases. Mattson found the clay particles were negatively charged and as the suspending medium was made acid the velocity decreased, and with a further increase in acidity the particle became positively charged. Thus the iso-electric point is passed on the acid side. The addition of alkali to a clay suspension increases the negative charge on the particles until a certain point is reached where further addition of alkali decreases the charge on the particles. This point of maximum charge occurs in the region of maximum deflocculation. The point of maximum rate of settling occurs at the iso-electric point where the charge on the particles is zero. The point of maximum deflocculation occurs at the point where the particles have the maximum charge. This seems to be a good explanation of the action of acids and alkalies on clay suspensions.

¹ Received August 1, 1923.

² "Die Beziehungen zwischen Ausflockung, Adsorption und Teilchenladung mit besonderer Berücksichtigung der Hydroxylionen," *Kolloidchemischen Beiheften*, **14** [9-12], 272.

THE CHEMISTRY OF THE TERPENE MEDIUM FOR CERAMIC LIQUID GOLD

BY P. P. BUDNIKOFF AND E. A. SHILOV

The preparation for gilding ceramic wares was invented by Doctor Kühn in Meissen. Due to its highly valuable qualities this preparation very soon won a universal renown. The golden powder, which previously was used exclusively, besides being very expensive, had many inconveniences.

The principal substances used for the preparation of gold for overglaze gilding of pottery through fire are turpentine,¹ lavender and other oils, sulphur and gold chlorides. Turpentine is boiled with 20% of sulphur in an oil bath under a return condenser for several hours. To the reaction product obtained ("sulphury balsam"), gold chloride is added. In order to fasten the gold on to the surface of the pottery, a small quantity of flux is added.²

One of the principal conditions for a proper formation of a glazing golden coating after burning is that the gold must remain in a colloidal solution.

On the basis of our experimental work, we became convinced that (1) no solid compounds whatever, *i. e.*, precipitates containing gold such as gold sulphide, gold mercaptide etc., mixed with fluxes would produce a glazing coating; and (2) that no solution of gold compounds would produce a glazing lamina. It seemed necessary to have the gold in a compound that would be changed into gold sulphide just at the moment the heat caused the solvent to disappear. Such complex compounds of gold as the thio derivatives of the terpenes in solution (probably colloiddally) in excess of solvent seemed to fulfill such requirements. Our experiments have proved to us the nature of these thio derivatives of terpenes.

After several hours of boiling sulphur with terpenes,³ we observe a plain, dense, brownish-red liquid with a sharp specific odor, and soluble in many common organic solvents. This reaction is accompanied by the scanty productions of H_2S .⁴ When heated in a vacuum or under atmospheric

¹ The Russian turpentine, as our studies have proved is not fit for such a purpose, for it possesses reducing qualities. In a given preparation, gold precipitates little by little in the shape of metallic gold which can easily be observed through a microscope. The lamina after burning in the muffle acquires in the latter case a dead gold surface.

² Duterte. Dingler's *Polyt. Tourn.*, **161**, 44, **182**, 265; Carre, Sulvetat in Brogniart Tr., **11**, 721; Schwarz, Dingler's *Polyt. Tourn.*, **197**, 243; Gentile, Wagner's *Tahresberichte* (1856), 178; P. Budnikoff, The News of Tvanovo-Voznessensk, *Polytech. Inst.*, **6**, 211 (1922).

³ We began the study of this reaction with the chemically pure pinene (boiling point 155–156°C) rectified over metallic sodium in an atmosphere of CO_2 but because of the Russian conditions we were obliged to adapt the Russian turpentine, choosing the fraction 170–175°C.

⁴ When boiling 3% of sulphur solution in turpentine for 70 hours, about 2½% of the sulphur employed is transformed into hydrogensulphide.

pressure, it was observed that the higher the boiling point, the greater its sulphur content. (See Tables I, II, and III.)

TABLE I

DATA PRODUCT AFTER DISTILLING IN VACUUM

Substance	Pressure	Boiling point	Refrac- tion	Disper- sion	Content of sulphur	Weight
Terpene.....	750 mm.	155-156°	1.467	39.5		240 gr.
Product of reaction.....			1.560	38.7		
1st fraction.....	20	60-70°	1.474	38.9	0.4%	17 gr.
2nd fraction.....	15	70-90°	1.484	38.5	3.9%	15 gr.
3rd fraction.....	15	90-120°	1.494	37.75	6.4%	44 gr.
4th fraction.....	15	120-140°	1.530	36.3	14.6%	32 gr.

TABLE II

PRODUCT RECTIFIED BY ATMOSPHERIC PRESSURE

Substance	Boiling point	Refraction	Dispersion	Content of sulphur	Weight
Terpene.....	170-175°	1.4739	39.4		
Product of Reaction.....		1.560	38.3		350 gr.
1st Fraction.....	160-175°	1.469	39.2	3.91%	101 gr.
2nd Fraction.....	175-185°	1.481	38.9	7.62%	42 gr.
3rd Fraction.....	185-200°	1.490	38.6	9.64%	36 gr.
4th Fraction.....	200-210°	1.548	38.4	12.76%	13 gr.

TABLE III

PRODUCTS ACQUIRED IN ATMOSPHERE OF CO₂

Substance	Boiling Point	Per cent Content S	Weight
Terpene.....	155-156°		
Product of Reaction with Sulphur in the Atmosphere CO ₂			350 gr.
1st Fraction.....	147-161°	3.0	112 gr.
2nd Fraction.....	161-165°	4.6	29 gr.
3rd Fraction.....	165-170°	11.8	10 gr.
4th Fraction.....	170-200°	13.1	16 gr.

About 50% of turpentine remains in the distillational flask in the shape of pitch, little fit for investigation. We did not succeed in obtaining a substance with a constant boiling point from the products of the reaction.

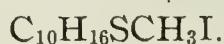
In 1908 Erdmann¹ tried to explain the reaction between sulphur and the terpenes. As a starting point he took the hypothesis that the group S₃, (analogous to ozone) combines with many chemical compounds. By the action of sulphur on the products of terpenes at a high temperature the group S₃ is always combined in the place of the double bond giving as result compounds which he calls thiozonides.

Thus, only one molecule of terpene can be united with three or its multiple number of atoms of sulphur. Erdmann states that there can be no other compounds. As much as we can judge, Erdmann did not succeed

¹Liebig's, *Annalen*, 362, 133.

in obtaining individual chemical compounds by which he could justify his point of view. Our investigations¹ did not confirm Erdmann's opinions, for we did succeed in obtaining one definite chemical compound containing one atom of sulphur for one molecule of terpene. We obtained it by treating the reaction products with CH_3I at ordinary temperature whereby fine crystals precipitated little by little. These we found could be dissolved in absolute alcohol and precipitated by ether. This compound melts with decomposition at about 121°C , but at a lower temperature it becomes brownish. We must remember that we had not the definite terpene but a mixture.

The ultimate analysis shows that the crystalline precipitate from the interaction of CH_3I on the reaction product between sulphur and the terpenes corresponds in its composition to the formula:



0.1500 gr. of substance gave 0.0799 gr. H_2O and 0.2337 gr. CO_2

0.1000 gr. of substance gave 0.0755 gr. AgI

0.2380 gr. of substance gave 0.1718 gr. BaSO_4 (Liebig²)

0.1880 gr. of substance gave 0.1239 gr. BaSO_4 (Dennstedt)

Found:	Calculated for $\text{C}_{10}\text{H}_{16}\text{SCH}_3\text{I}$:
C—42.50%	42.57%
H— 5.99%	6.17%
I— 40.50%	40.92%
S— 9.90%	
S— 9.52%	

This compound, as we shall see, further appears to be a typical sulphonium salt, and that is the reason that we called it methylterpensulphonium-iodide.

This iodide is easily soluble in water, but decomposes slowly when boiled. It contains iodine in a ionogen state: when AgNO_3 is added the halogen is quickly precipitated in the form of AgI . Its solution in water conducts the electric current just as well as solution NaI . [The molecular conductivity $\text{C}_{10}\text{H}_{16}\text{SCH}_3\text{I}$ at 25°C (1/100 N) = 114,⁷ NaI = 112⁵ (1/128 N).]³

With moist silver hydroxide it gives a strong base, which precipitates the heavy metals and liberates ammonia from compounds. This base,

¹ P. Budnikoff and E. A. Shilov, "About the Action of Sulphur and Sulphur Compounds on the Terpenes," News of Tvanovo Vosnessensk, *Polytechnical Institute*, No. 4, 6, 7 (1921–1922).

² It is interesting to observe that the acidation at the rate of L. Carius can be produced with great difficulty, even when heating to 300°C with HNO_3 of density 1.52 for 20 hours. It is evident that sulphones are produced which are transformed with difficulty into sulphuric acid.

³ Landolt, p. 1112. Latest ed.

$C_{10}H_{16}SCH_3I.HgI_2$ calculated for	Found:
Hg— 26.18%	26.27%
I— 49.85%	49.82%

The compound of methylterpensulphoniumiodide with two molecules of mercury iodide is also easily obtained if we take calculated quantities of components in acetone solution. Having evaporated the acetone in the vacuum, we obtained, when seen in the microscope, lemon-yellow, elongated, oblique prisms.

For the preparation of the complex $C_{10}H_{16}S.CH_3I_2HgI_2$, 0.746 grams of $C_{10}H_{16}S.CH_3I$ were dissolved in 40 cc. of acetone, by slight heating. We then added 2.183 grams of HgI_2 , whereby all the mercury iodide passed into the solution. The yellowish precipitate obtained was filtered, then evaporated in a flat crystallizing dish, filtered, washed in a mixture of 1 volume of acetone with 2 volumes of ether and dried in the open air.

$C_{10}H_{16}S.CH_3I.2HgI_2$ decomposes at a temperature somewhat higher than $100^\circ C$. It is rather readily soluble in acetone, less soluble in alcohol and slightly soluble in chloroform and ether. It is insoluble in water, but is destroyed in a dilute solution of potassium iodide, yielding a pale yellow precipitate which probably is the compound of methylterpensulphoniumiodide with one molecule of mercury iodide.

0.1847 gr. of substance gave 0.1773 gr. AgI
0.1352 gr. of substance gave 0.0512 gr. HgS

$C_{10}H_{16}S.CH_3I.2HgI_2$ calculated for	Found:
T— 51.69%	51.89%
Flg— 32.58%	32.63%

According to this method we can add AsI_3 to the methylterpensulphoniumiodide and obtain good orange or deep red crystals, soluble in acetone and alcohol.

$C_{10}H_{16}S.CH_3I.AsI_3$ is soluble in water, giving a colorless solution that has an acid reaction. This indicates a decomposition of this complex compound in the water.

0.2023 gr. of substance gave 0.2666 gr. AgI
0.1733 gr. of substance gave 0.0260 gr. As_2S_3

$C_{10}H_{16}SCH_3I.AsI_3$ calculated for:	Found:
I— 66.2%	65.4%
As— 9.7%	9.1%

The double salt of arsenic iodide with methylterpensulphoniumiodide oxidizes easily in the air, yielding As_2O_3 .

The solution of $AuCl_3$ in alcohol precipitates black crystals of $C_{10}H_{16}S.CH_3I.AuI_3$ from solution of methylterpensulphoniumiodide.

Calculated:	Found:
Au 22.2	22.4

Accordingly we can consider it proved that the sulphur, when acting on the terpenes, gives terpenmonosulphide.

If we add to the distillates some "sulphury balsam" spirit solutions of salts of heavy metals (AuCl_3 , PtCl_4 , $\text{Pb}(\text{CH}_3\text{COO})_2$, HgCl_2 and others) we obtain rather slightly soluble precipitates which are unsuited for analysis.

In these complex compounds the metal is immediately combined with the sulphur of the terpenmonosulphide. When heated or acted on by steam they produce a metal sulphide. If we prepare such a precipitate with gold chloride and coat glazing pottery with it, we shall obtain, after calcination, a bright coating of gold. Evidently the grains of this product are too big. In the industries, in order to obtain a preparation of gold, the "sulphury balsam" must act on the water solution of gold chloride, whereby the gold chloride which enters slowly into chemical combination with terpensulphides, being extracted from the water solution, will not precipitate, if the "sulphury balsam" is properly prepared, but remain in solution probably as a colloidal suspension. In the latter case the grains of the complex compound of gold are so small that when heated in a muffle to $250\text{--}300^\circ$ we see a black mirror of gold sulphide coating the pottery, which upon further heating passes into SO_2 and Au in the shape of a fine bright crystalline coating.

We can obtain monosulphide $\text{C}_{10}\text{H}_{16}\text{S}$ with far better success by the action S_2Cl_2 on the terpenes. The reaction goes on vigorously in the cold. After heating the products of reaction in an oil bath under a reflux condenser for several hours, CH_3I precipitates the same methylterpen-sulphoniumiodide, and approximately in double the quantity as when free sulphur is used. At the same time the terpenes react with chlorine, since during the reaction hydrogen chloride is abundantly evolved. On the sides of the flask at the top of the liquid, after cooling, white crystals of pinenechlorhydrate are produced which have a melting point of 131° . Adding to the fractions of the product obtained an alcoholic solution of AuCl_3 , a red thick oil separates out.

This oil, dissolved in turpentine, gives after calcination a fine crystalline golden coating on the pottery.

The chlorinated terpenes appear to be good non-reducing solvents for the complex compounds of gold chloride and the thioderivatives of terpenes.

It is interesting to observe that with this method of preparing a liquid preparation of gold, we can use Russian turpentine, because S_2Cl_2 appears to be an oxidizing agent for the reducible substances in Russian turpentine.

For the preparation of "sulphury balsam," Paul Koch in a German patent N. 219,121¹ and N. 236,490² points to the possibility of using the

¹ Friedlander IX, 1094, *Fortschritte der Teer farbenfabrication*.

² *Ibid.*, 1305.

polysulphides of sodium and potassium but he did not isolate the terpen-monosulphides and did not even state the possibility of their formation. Although we did not note an important increase of sulphur in the products of distillation, we did obtain a reaction at 120° which produced a smaller quantity of pitch. Perhaps the further study of this method will give more satisfactory results.¹

NOTE: The authors wish to express their most sincere gratitude to the assistant, N. T. Voznessensky, who assisted in this work.

¹ If we boil the polysulphides with the terpenes under a reflux condenser for a longer time the products of reaction will produce a sulphur dyestuff of a chocolate color.

IVANOV-VOZNESSENSK, POLYTECHNICAL INSTITUTE,
LABORATORY OF MINERAL TECHNOLOGY.
NOVEMBER, 6 1922.

PANEL TESTS OF LIME PLASTER¹

BY W. E. EMLEY AND E. B. BERGER

A previous research on this subject² indicated that the popping which sometimes occurs as a defect in lime plaster is caused by the slow hydration and expansion of certain impurities which might be present in the lime or sand. It seemed that large particles of almost any substance, even though it were not subject to hydration, might work loose and fall out, leaving an unsightly hole in the plaster. Small particles, on the other hand, do not usually cause trouble, even though they are susceptible to hydration and expansion. It seems that the small particles hydrate before the plaster has set, or the magnitude of the expansive force is not sufficient to loosen the particle, or, if the particle does fall out, the hole which it leaves is too small to be readily noticeable.

On the basis of the above, a proposal was made to require hydrated lime to be of such fineness that it would all pass a No. 50 sieve. But before accepting such a radical proposal, it was felt that a much more extensive investigation should be made.

Accordingly, under the sponsorship of the Lime Committee of the A.S.T.M., 98 panels of lime plaster have been erected at this Bureau. The Bureau conducted the necessary laboratory work to show the quality of the materials, furnished the space for the panels, and made the examination of their condition. The panels were erected by the Contracting Plasterers National Association, of materials furnished by the National Lime Association, and the plaster was applied by the Operative Plasterers International Union. The work was completed on March 4, 1922.

Prior to the application of the plaster, thirteen brands of hydrate were examined chemically and microscopically. From the information thus obtained, and from similar examinations of sands, certain impurities were selected as being likely to be present and to cause trouble. One of these materials, for example, was calcium carbonate in the form of "core". Some "core" was obtained from a lime manufacturer, ground, and screened to three sizes: all through a No. 14 sieve and retained on a No. 30 sieve; all through a No. 30 sieve and retained on a No. 50 sieve; and all through a No. 50 sieve. One of the hydrates was selected, and used as a finish coat for one panel, permitting the plasterer to use his own judgment about consistency and gaging with gypsum. A mixture of 9 parts by weight of this hydrate with 1 part of the coarse core was used for the second panel. In the same manner, medium and fine core was added to the finish coat for the third and fourth panels respectively. Each panel

¹ Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce. Recd. May 9, 1923.

² W. E. Emley and C. H. Bacon, "Soundness of Lime Plaster," *Jour. Amer. Ceram. Soc.*, **3** [11], 877 (1920).

was duplicated, as a check, and the same procedure was followed for each of the impurities selected.

The panels became one year old on March 4, 1923. Their condition at that date was as follows:

Hydrate No. 1 (Ohio), plus core.
Panels Nos. 1 to 4 and 50 to 53.

All panels in good condition, showing that the presence of core, even though coarse, is not deleterious.

Hydrate No. 2 (Ohio), plus sand.
Panels Nos. 5 to 8 and 54 to 57.

All three sizes of sand caused popping, but the duplicate panels did not check this, except in the coarse size. The coarse size causes popping more quickly than the fine. It seems that differential expansion and contraction causes the sand grains to become loose and fall out.

Hydrate No. 3 (Ohio), plus over-burned lime.
Panels Nos. 9 to 12 and 58 to 61.

This over-burned lime was so badly over-burned as to be hard and yellow, and it could be immersed in water for six hours without noticeable effect. The hydrate itself was slightly unsound, as evidenced by a few small pops in the plain panels. The effect of the over-burned lime is very marked. In the fine size, it has produced blisters; in the coarse size, it has caused complete disintegration of the finish coat.

Hydrate No. 4 (Pennsylvania), plus magnesia.
Panels Nos. 13 to 16 and 62 to 65.

The hydrate itself shows a few pops, and the magnesia is apparently without effect. This is "light calcined" or "caustic" magnesia, which probably hydrated when the lime was soaked before use. Hydrates Nos. 1, 2, 3, 4, 6, 9, and 11 are dolomitic, and contain the usual hard burned magnesia.

Hydrate No. 5 (Vermont), plus iron carbonate.
Panels Nos. 17 to 20 and 66 to 69.

The hydrate itself shows a few pops and cracks. The additions of iron carbonate seem to have no effect.

Hydrate No. 6 (Ohio), plus quicklime.
Panels Nos. 21 to 24 and 70 to 73.

This hydrate also was not entirely sound. The quicklime used was well burned, quick slaking material. Probably most of it hydrated during the soaking prior to use. The fine quicklime shows no noticeable effect; the medium shows a few additional pops; and the popping of the coarse particles is quite apparent.

Hydrate No. 7 (Texas), plus pyrites.

Panels Nos. 25 to 28 and 74 to 77.

The plain hydrate panels, and those with fine pyrites, show traces of popping. The medium and coarse particles of pyrites show distinct evidence that they will cause popping, the time required for the pop to appear depending upon the size of the particle.

Hydrate No. 8 (California), plus magnesium sulphate.

Panels Nos. 29 to 32 and 78 to 81.

This impurity seems to have no effect. All panels are in good condition.

Hydrate No. 9 (Pennsylvania), plus sodium chloride.

Panels Nos. 33 to 36 and 82 to 85.

The hydrate shows traces of unsoundness, which are not increased by the impurity. However, sodium chloride produces efflorescence, which is very bad when the material is fine, but not so bad with the coarse salt.

Hydrate No. 10 (Maine), plus lime burned during hydration.

Panels Nos. 37 to 40 and 86 to 89.

The term "lime burned during hydration" is used to describe the coarse hard particles produced when lime is hydrated with an insufficient amount of water. This material was made in the Bureau laboratory. The coarse particles caused a few pops; with the medium size, the pops are almost negligible; and the fine material caused no popping.

Hydrate No. 11 (Ohio), (Panels 41, 42, 90 and 91).

Plus mica (fine) Nos. 43 and 92.

Plus tannic acid (fine) Nos. 44 and 93.

The mica had no effect. Tannic acid retards the setting of the lime so much that the panels remained soft for two months. The surface is badly checked and discolored.

Hydrate No. 12 (Tennessee), plus clay.

Panels Nos. 45 to 48 and 94 to 97.

The clay used is known as Tennessee ball clay, and is quite plastic. The hydrate itself was not entirely sound. The clay, in medium or coarse sizes, may have caused some cracking. The fine size had no effect.

Hydrate No. 13 (Missouri).

Panels Nos. 49 and 98.

This hydrate was noticeably unsound.

Summary

No deleterious effect was produced by adding to the finish coat 10% by weight of core, magnesia, iron carbonate, magnesium sulphate, mica, or clay.

Particles coarser than a No. 50 sieve are apt to cause trouble if the material added is sand, quicklime, pyrites, or lime burned during hydration.

Overburned lime, salt, or tannic acid is bad regardless of the size of the particles.

The length of time required for popping to develop depends upon the size of the particles. Of the 13 hydrates used, eight showed some pops, which usually appeared about the end of the fifth month. This tendency to unsoundness is exaggerated by the severity of the examination to which the panels were subjected, and is of no commercial significance.

Conclusions

The following principles are recommended as the basis for a specification covering the soundness of hydrated lime or lime putty:

Examine microscopically to insure the absence of calcium oxide (index of refraction = 1.81).

Wash the sample through a No. 50 sieve. Dry and weigh the residue and figure it as per cent of the sample. If the residue is more than 5%, it should be analyzed. If this is found to be anything other than calcium carbonate, the sample should be rejected.

Pyrites can hardly occur in lime; but may be a constituent of the sand. A specification for sand is required, which should also carry limits on the quantity of salt and organic matter permissible.

² B. T. Sweely, Ceramic Engineer, Coonley Mfg. Co.

4. For greatest resistance to thermal shock, the ware should be coated with a ground coat having a coefficient of expansion equal to or preferably greater than that for the cover enamel.

5. Acid resistance, while dependent on the enamel composition, is not affected in the same way for all enamels. For these particular cover enamels, resistance to acids decreased with replacements of boric oxide by sodium oxide.

Introduction

The subject of resistance of enameled ware to impact is of interest to manufacturers of all enameled products. Other properties are of importance in particular lines. In the manufacture of kitchen ware, such factors as the resistance to thermal shock and the resistance to corrosive action of certain foods are of equal importance.

Review of Literature

The literature on enameling contains many references to the testing of enameled wares.

Orton¹ reported on some tests of automobile tags for resistance to acids, thermal shock, impact, and bending. Since these tests were made on commercial enameled ware, no attempt was made to draw any conclusions as to the relation between enamel compositions and the chemical and physical properties. Orton makes reference to the circularized reports of Hooper on tests of enameled kitchen ware, but these evidently made no mention of the methods employed except in the case of tests of acid resistance.

Shaw and Shaw² followed Orton with the first investigation on the relation of the composition to the properties of some white cover enamels. They obtained important information on the relation of composition to solubility in acids, but they make no mention of the relation existing between composition and the physical properties.

Landrum,³ comparing ten white enamels, describes in detail methods for the testing of white enameled kitchen ware. Since the tests were made on enamels which bear no definite relation to each other, and in some cases at least are not enamels which could be used commercially, Landrum did not discuss any relationships between composition and properties. The report is valuable because of its exposition of various methods suitable for the testing of commercial enameled kitchen ware.

¹ Edward Orton, Jr., "Testing of Enameled Sheet Steel Wares," *Trans. Amer. Ceram. Soc.*, **11**, 320 (1909).

² J. B. and L. Shaw, "Testing Sheet Steel Enamels," *Trans. Amer. Ceram. Soc.*, **12**, 463 (1910).

³ R. D. Landrum, "Comparison of Ten White Enamels for Sheet Steel," *Trans. Amer. Ceram. Soc.*, **14**, 489 (1912).

Poste,¹ Landrum² and Frost³ have done considerable work on the testing of acid resistance of enameled ware with special reference to the types of acid and methods most suitable for such tests.

An investigation on the relations between the composition of ground coats and their resistance to impact has been reported by one of the authors of this paper.⁴ This gives some information on the effect of metallic oxides and silica on the resistance of ground coats to impact. The tendency of cobalt oxide to increase the toughness of ground coats has also been shown by Landrum.⁵

The relation of composition of enamels to their solubility in acids as applied to enamels on cast iron chemical ware was reported by Staley.⁶

In a discussion on "The Relation of Composition to Thermal Shock in Steel Enamels," Sweely⁷ called attention to the apparent importance of the relation of expansion of the ground and cover coats on the resistance of enameled ware to thermal shock.

Plan of Investigation

In view of the results obtained by Sweely in a few simple experiments with three enamels of different expansivities, it was planned to conduct an extended investigation along the lines suggested to determine what relations, if any, existed between "fit" of the enamels and their resistance to impact and to thermal shock.

The work as outlined consisted in the preparation of a series of ground coat and white cover enamels, so compounded as to give a range of expansivities from values considerably below that for steel to values equal to that for the metal. This was most easily accomplished by selecting an enamel high in boric oxide and replacing the latter by sodium oxide. This procedure made it impossible to plan enamels of commercial types although some fell within the range of expansivities common to commercial enamels.

The theoretical coefficients of expansions of the enamels were calcu-

¹ E. P. Poste, "Relative Action of Acids on Enamels," *Trans. Amer. Ceram. Soc.*, **17**, 137 (1915); **18**, 762 (1916); *Jour. Amer. Ceram. Soc.*, **2**, 32 (1919); **3**, 560 (1920).

² R. D. Landrum, "Resistance of Sheet Steel Enamels to Solution by Acetic Acids of Various Strengths," *Trans. Amer. Ceram. Soc.*, **13**, 494 (1911).

³ L. J. Frost, "Action of Acetic Acid Solutions on Sheet Steel Enamels," *Jour. Amer. Ceram. Soc.*, **1**, 422 (1918).

⁴ R. R. Danielson, "Effect of Variation in Composition of Ground Coats for Sheet Iron Enamels," *Trans. Amer. Ceram. Soc.*, **18**, 343 (1916).

⁵ R. D. Landrum, "Necessity of Cobalt in Ground Coat Enamels for Sheet Steel," *Trans. Amer. Ceram. Soc.*, **14**, 756 (1912).

⁶ H. F. Staley, "Some Relations of Composition to Solubility of Enamels in Acids," *Jour. Amer. Ceram. Soc.*, **4**, 703 (1921).

⁷ B. T. Sweely, "Relation of Composition to Thermal Shock in Steel Enamels," *Jour. Amer. Ceram. Soc.*, **5**, 263 (1922).

lated from the theoretical melted composition of the frit according to the values assigned to the oxides by Mayer and Havas,¹ and checked by the Expansivity Section of the Bureau of Standards.

Preparation of Enamels

The melted compositions of the ground coats and cover enamels studied with their theoretical calculated coefficients of expansion are shown in Tables I and II.

TABLE I
MELTED COMPOSITION OF GROUND COATS

Ground coat no.	Feldspar	Melted frit—percentage of oxides					Calcd. linear coeff. of expansion
		Boric oxide	Cryolite	Sodium oxide	Fluorspar	Cobalt oxide	
C-2	60	24	11	0	4	1	0.0000084
C-5	60	21	11	3	4	1	.0000094
C-8	60	18	11	6	4	1	.0000103
C-11	60	15	11	9	4	1	.0000114
C-14	60	12	11	12	4	1	.0000124
C-17	60	9	11	15	4	1	.0000133
C-20	60	6	11	18	4	1	.0000143

TABLE II
MELTED COMPOSITION OF WHITE COVER ENAMELS

Cover enamel no.	Feldspar	Quartz	Melted frit—percentage of oxides				Calcd. linear coeff. of expansion
			Boric oxide	Cryolite	Sodium oxide	Fluorspar	
B-1	50	10	22	12	1	5	0.0000083
B-4	60	0	21	12	2	5	.0000092
B-7	60	0	18	12	5	5	.0000102
B-10	60	0	15	12	8	5	.0000112
B-13	60	0	12	12	11	5	.0000122
B-16	60	0	9	12	14	5	.0000132
B-19	60	0	6	12	17	5	.0000142

TABLE III
BATCH WEIGHTS OF GROUND COATS

Ground coat no.	Feldspar	Batch weights for 100 lbs. of frit						Black cobalt oxide
		Boric acid	Borax	Cryolite	Soda nitrate	Soda ash	Fluorspar	
C-2	60	42.5	0	11	0	0	4	1
C-5	60	37.2	0	11	5.5	1.7	4	1
C-8	60	16.2	24.3	11	5.5	0	4	1
C-11	60	0	41.0	11	6.1	0	4	1
C-14	60	0	33.0	11	5.5	7.8	4	1
C-17	60	0	24.6	11	5.5	15.3	4	1
C-20	60	0	16.4	11	5.5	22.7	4	1

¹ Mayer and Havas. See *Sprechsaal*, 42, 497; 44, 188, 207, 220. (A list of values for the oxides ordinarily used in enameling is given in "Enamels," by R. D. Landrum and published by Harshaw, Fuller & Goodwin Co. A partial list is also given in Bureau of Standards, *Technologic Paper* 142.)

The batch weights for the various enamels are given in Tables III and IV.

TABLE IV
BATCH WEIGHTS OF WHITE COVER ENAMELS
Batch weights for 100 lbs. of frit

Cover enamel No.	Feldspar	Quartz	Boric acid	Borax	Cryolite	Soda nitrate	Soda ash	Fluorspar
B-1	50	10	39	0	12	2.75	0	5
B-4	60	0	37.2	0	12	5.50	0	5
B-7	60	0	20.1	18.2	12	5.50	0	5
B-10	60	0	3.01	36.3	12	5.50	0	5
B-13	60	0	0	33.0	12	5.50	6.1	5
B-16	60	0	0	24.6	12	5.50	13.6	5
B-19	60	0	0	16.5	12	5.50	21	5

These enamel ingredients, which it was believed tend to show the greatest variations, were analyzed with the following results:

TABLE V

Connecticut feldspar		Borax	Per cent	Boric acid	Per cent
Silica	68.69	Na ₂ O	16.91	B ₂ O ₃	55.83
Alumina	17.57	B ₂ O ₃	36.56	H ₃ BO ₃	98.76
Potassium oxide	10.20	Cl	Trace	Insol.	Trace
Sodium oxide	2.70	SO ₃	Trace	Cl	Trace
Calcium oxide	Trace	Na ₂ B ₄ O ₇	99.65	SO ₃	Trace
Magnesium oxide	Trace				
Loss on ignition	0.44				
	99.60				

The raw materials were mixed thoroughly in batches of about 20 pounds and smelted in a gas-fired smelter (Fig. 1) having a hearth about 12 inches square. The time of smelting averaged about 60 minutes. The batch was occasionally stirred to promote quick melting of the charge.

The enamels were milled in approximately 10 pound batches, with the following mill additions for approximately 7 hours.

TABLE VI

Ground coats		White cover enamels	
Frit.....	10 lbs.	Frit	10 lbs.
Clay.....	7.0%	Clay.....	7.0%
Borax.....	1.5%	Tin oxide.....	6.0%
Water.....	50.0%	Magnesium carbonate...	0.5%
		Water.....	50.0%

Properties of Enamels

Expansivity.—Expansivity determinations on the various enamels were made by the Expansivity Section of the Bureau. These determinations were made on the milled enamels as ready for application to the steel plates. The method of preparing the enamels and the method of deter-

mining the expansivity were as has been described by Danielson and Souder.¹

While the expansivity tests were made over the range 450° to 20°C (842° to 68°F), it was found

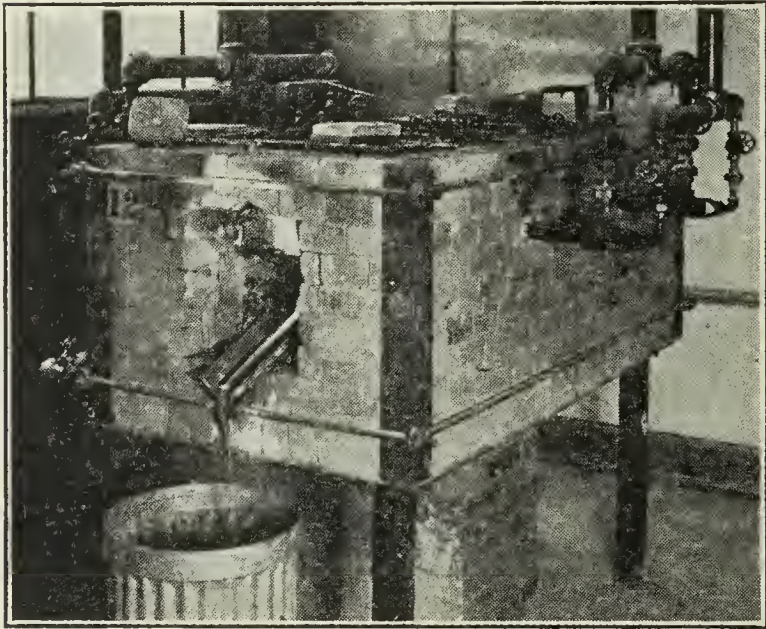


FIG. 1.—Smelter used in melting enamel batches.

that a number of the enamels softened at temperatures around 450°C (842°F), giving erratic results, so that the final determinations were made over the temperature range 400° to 20°C (752° to 68°F). The Bureau's observed values are shown in Tables VII and VIII in comparison with the values calculated from the theoretical composition of the frit as suggested by Mayer and Havas. The comparative expansivities

of the ground and the cover enamels are shown in Fig. 2.

TABLE VII

Ground coat no.	COEFFICIENT OF EXPANSION OF GROUND COATS	
	Average coefficient of expansion per °C	
	Bureau values	Values calcd. from frit compn.
C-2	0.0000088	0.0000084
C-5	.0000093	.0000094
C-8	.0000111	.0000103
C-11	.0000117	.0000114
C-14	.0000118	.0000124
C-17	.0000124	.0000133
C-20	.0000141	.0000143

TABLE VIII

White cover enamel no.	COEFFICIENT OF EXPANSION OF COVER ENAMELS	
	Average coefficient of expansion per °C	
	Bureau values	Values calcd. from frit compn.
B-1	0.0000088	0.0000083
B-4	.0000095	.0000092
B-7	.0000106	.0000102
B-10	.0000112	.0000112
B-13	.0000116	.0000122
B-16	.0000123	.0000132
B-19	.0000135	.0000142

¹ R. R. Danielson and W. H. Souder, "Causes and Control of Fish-Scaling," *Jour. Amer. Ceram. Soc.*, 4 [8], 620 (1921).

In the enamels containing high boric oxide, the observed values are higher than the calculated values, while in those containing excess sodium oxide the reverse is true. Boric oxide volatilization, of course, has less effect on the expansivity values than the volatilization of an equal weight of sodium oxide, since the value assigned to the latter by Mayer and Havas is one hundred times as great as that for boric oxide.

The calculated expansivity values are at the best only approximate, yet give important relative values.

Compression Strength of Enamels

In order to obtain data on the relation of composition to strength of the enamels, compression tests were made. For test specimens the melted

frit was cast in metal cylinders lined with asbestos paper. An attempt was made to mold the enamels containing the mill additions, but these were so viscous that homogeneous samples could not be obtained. After annealing the cylinders from 500°C (932°F) to room temperature, they were ground to size, about 1½ inch in diameter by

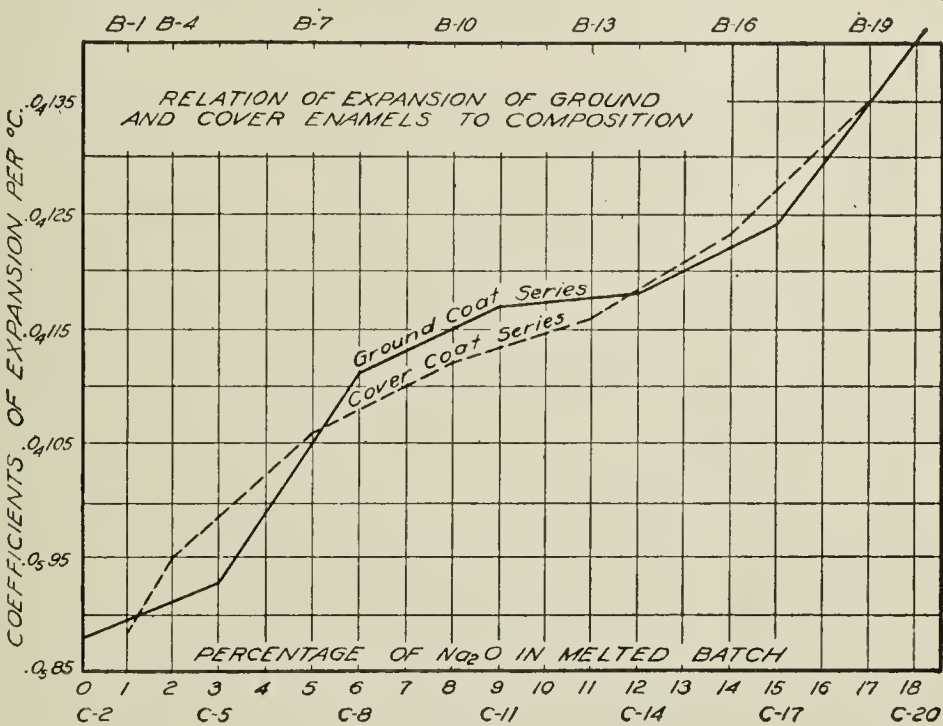


FIG. 2.

1 inch in length, and the ends were then surfaced perpendicular to the length.

The specimens were then tested in a 50,000-pound testing machine. During the application of the load up to about 1500 pounds, the deformation of the specimens was measured by means of miniature strain gages.

The results of the tests are given in Tables IX and X.

TABLE IX				
RESULTS OF COMPRESSION TESTS ON GROUND COATS				
Ground coat	Ultimate compressive strength in lbs. per sq. inch			Modulus of elasticity (in compression)
	High value	Low value	Average	
C-2	104,000	73,300	88,650	7,400,000
C-5	91,200	80,600	85,900	10,000,000
C-8	103,900	97,500	100,700	10,700,000
C-11	87,500	77,600	82,500	13,500,000
C-14	94,400	88,000	92,450	11,100,000
C-17	....	....	82,000	9,500,000
C-20	82,500	79,200	80,500	8,000,000
A commercial enamel	96,400	93,700	95,500	9,500,000

TABLE X
RESULTS OF COMPRESSION TESTS OF COVER ENAMELS
Ultimate compressive strength in lbs. per sq. inch

Cover enamel	High value	Low value	Average	Modulus of elasticity (in compression)
B-1	72,600	70,500	71,500	7,100,000
B-4	74,300	65,900	72,900	7,100,000
B-7	89,000	71,000	83,300	13,000,000
B-10	....	....	91,600	8,700,000
B-13	114,900	72,600	97,500	10,000,000
B-16	101,100	70,200	97,600	8,300,000
B-19	100,000	88,000	98,440	8,300,000
A commercial enamel	113,000	77,600	91,740	9,500,000

The values for the high and the average values are also plotted in Fig. 3, and the moduli of compressional elasticity for the various enamels are given in Fig. 4.

The results of these tests in some instances are erratic, due probably to structural flaws.

With the substitution of sodium oxide for boric oxide, the cover enamels show an increase in strength, an effect which is not observed in the

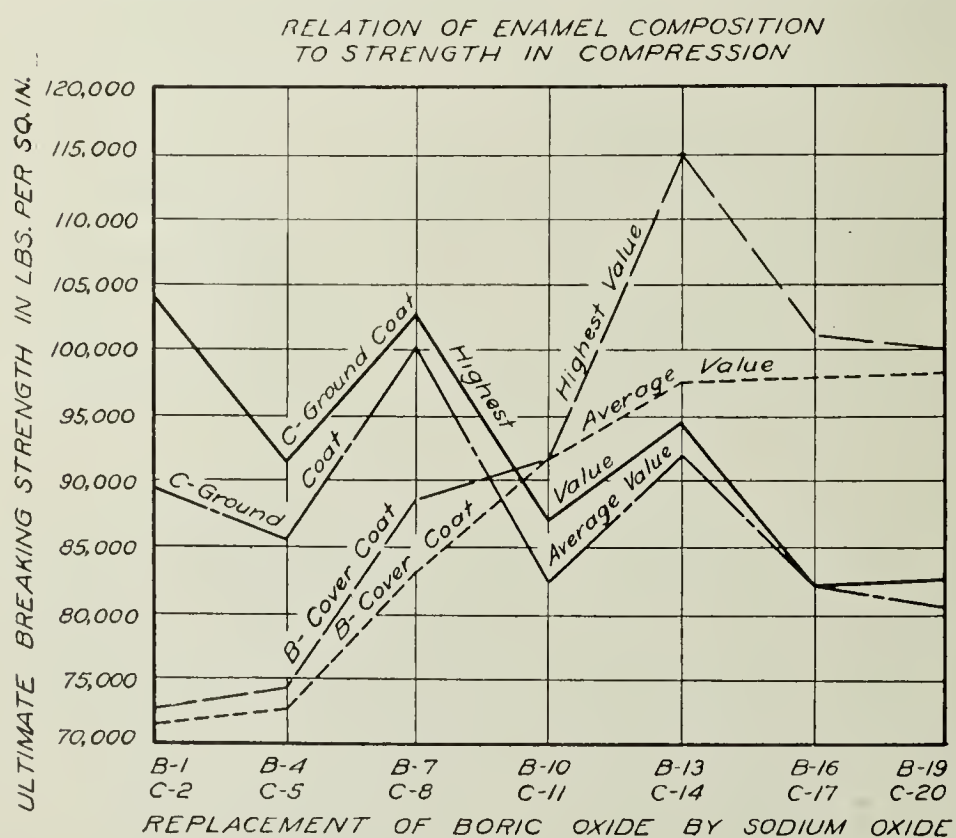


FIG. 3.

ground coats. The results for the latter are too erratic to permit of definite conclusions as to the effect of such substitutions although the high values indicate a decrease in compressive strength with sodium oxide. Thus the effect of changes in composition on compressive strength of the enamels would appear to be dependent on the type of enamel under investigation.

The modulus of elasticity increases with replacement of boric oxide by sodium oxide up to a certain point beyond which further replacements decrease the values. While apparently no conclusions can be drawn as to the relation between the modulus of elasticity and other physical properties of an enamel, it is interesting to note that the values obtained for these enamels approximate those given in various handbooks for the modulus of elasticity in tension of glass.

Further reference will be made to the values for ultimate strength of the enamels in the discussion of the results of the impact tests on the enameled plates.

Properties of the Enameled Ware Application of Enamels

The ground coats were applied by the dipping process to 8-inch dinner plates of 28-gage stock of the style shown in Fig. 5. The plates were first scaled and then pickled in a 5% solution of commercial hydrochloric acid. They were then dried in a gas-heated drier at a temperature of about 70°C (158°F).

Following the firing of the ground coat, ten plates in each ground were then coated with two applications of each cover enamel so that specimens having all possible variations in the relation of the "fit" of the ground and cover enamels were obtained.

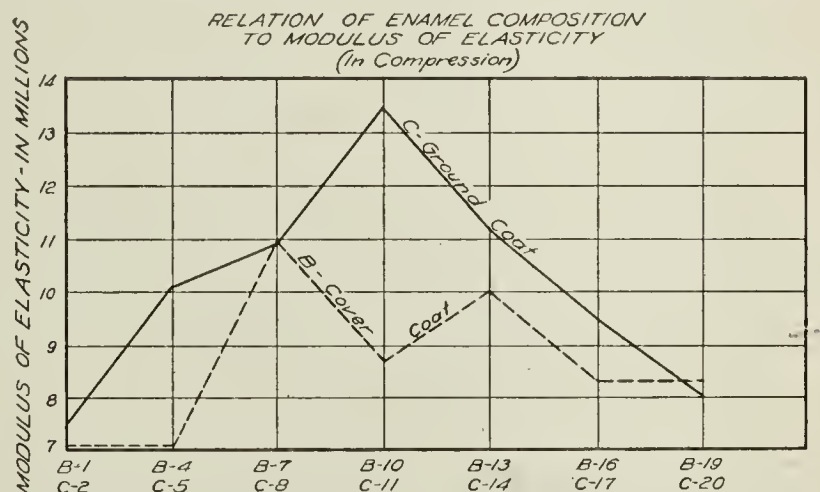


FIG. 4.

Firing of Ware

The plates were fired in a gas-fired muffle furnace (Fig. 6) with a floor 22" x 48". The plates were supported during firing on three-point racks, three plates to a load. A thermocouple was placed close to the ware. Because of the construction of the furnace and the arrangement of burners at the front and rear ends, it was possible to maintain quite uniform temperature conditions throughout the muffle chamber.

The following Tables XI and XII give the firing temperature and time required for the various enamels as well as the appearance of the enamel after firing:

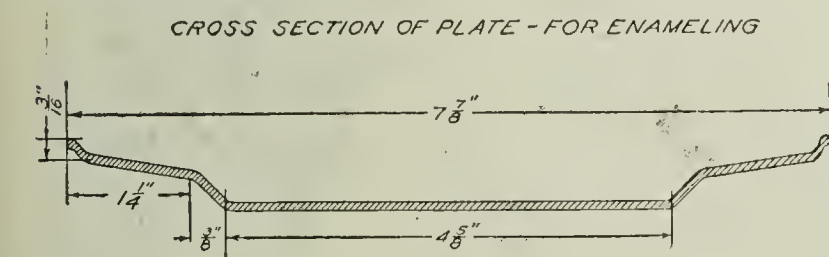


FIG. 5.

TABLE XI

DATA ON FIRING OF GROUND COATED PLATES

Ground coat no.	Temp., °F	Time, min.	Appearance of ground coat
C-2	1640	3	Fish-scaled badly—enamel crawled
C-5	1640	2 1/2	Fish-scaled—some crawling
C-8	1580	2	Slight fish-scaling—no crawling
C-11	1510	2 1/4	No fish-scaling—satisfactory
C-14	1510	2 1/2	No fish-scaling—satisfactory
C-17	1640	1	Slight crazing—slightly dull
C-20	1580	1	Badly crazed—dull finish

TABLE XII

DATA ON FIRING OF COVER ENAMELS ON PLATES

White enamel no.	Temp., °F	Time, sec.	Appearance of enamel
B-1	1615	70	Crawled badly—good white
B-4	1615	70	Crawled—good white
B-7	1600	70	Slight crawling—good white
B-10	1600	60	Satisfactory—medium opacity
B-13	1600	60	Satisfactory—medium opacity
B-16	1580	50	Satisfactory—poor opacity
B-19	1580	45	Crazed and dull—poor opacity

The decrease of fish-scaling with increase in the expansivity of the ground coats from C-2 to C-20 was very marked and gave further conclusive evidence of the accuracy of the previous findings in regard to the fundamental cause of fish-scaling.¹ It is also evident from these studies that

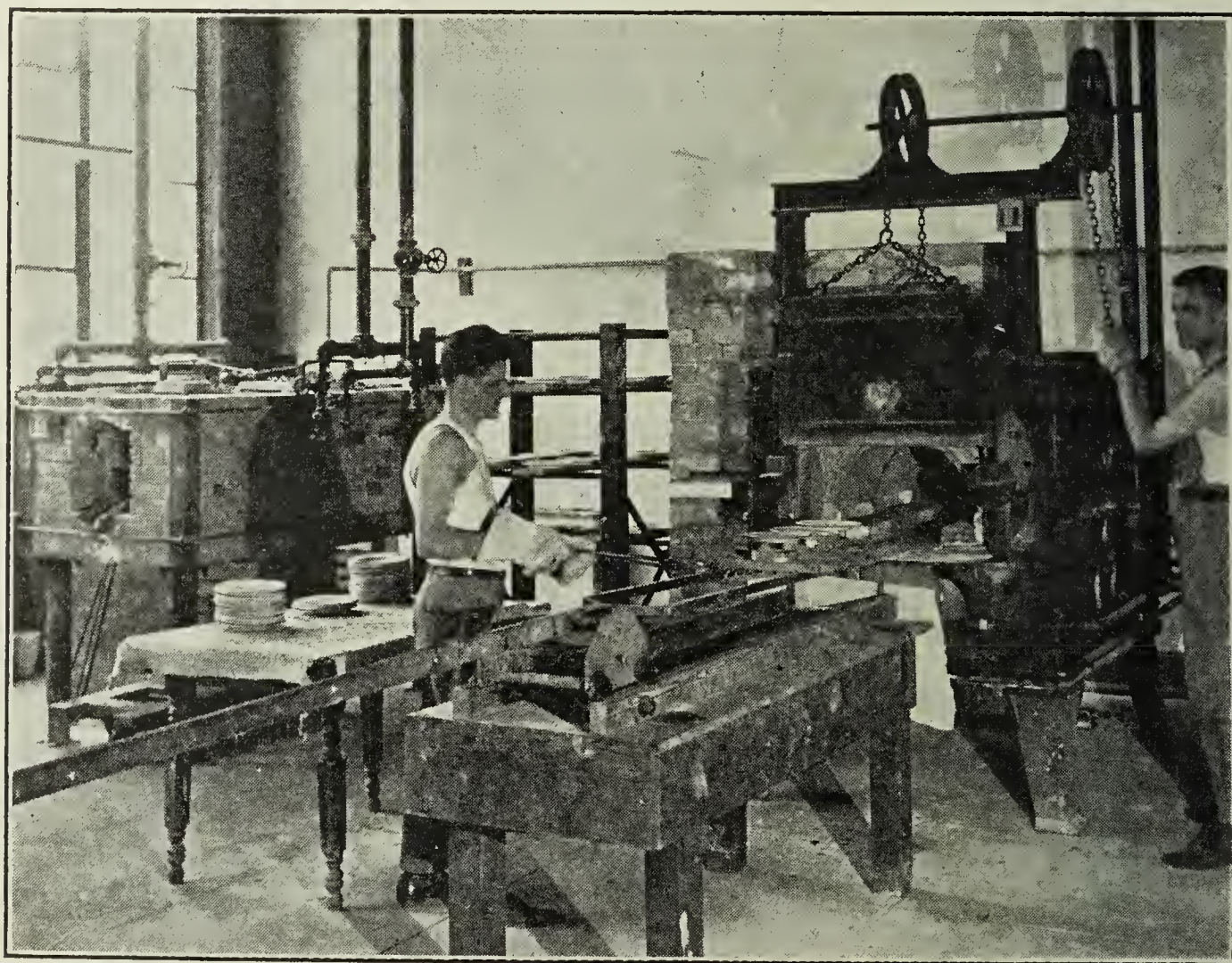


FIG. 6.—Muffle furnace for firing enameled ware.

the expansivity can be increased to a point where it is so high as compared with that for enameling steel that crazing will occur.

Excessive additions of boric oxide cause crawling, undoubtedly due to the extreme viscosity of these enamels. Substitution of boric oxide for

¹ "Causes and Control of Fish Scaling," *loc. cit.*

sodium oxide, however, tends to increase the burning range of the enamels. This is an important factor to the enameling process because of the rather poor heat distribution in the average enameling furnace as well as the tendency for thinner portions of a piece of ware to be fired too rapidly. These properties of boric oxide have been observed in various types of enamels.¹

The substitution of sodium oxide for boric oxide decreased the opacity of the enamels and tended to produce a dull matt texture.

Resistance of Enameled Plates to Impact

The enameled plates were tested for resistance to impact by a method which has been previously used at the Bureau in the tests of commercial kitchen ware. In this test, the plates were held firmly against a heavy board suitably fastened on uprights, with the bottom of the plate exposed to the impact hammer. The apparatus is shown in Fig. 7. The 6-ounce hardened steel hammer was allowed to swing through arcs of various angles, calibrated for blows of definite force in foot-pound. The initial blow was made at 0.075 foot-pound and this was increased 0.025 foot-pound at each succeeding blow.

Tests were made on the ware at two points. In the first, the impact was by a round steel hammer at the center of the bottom of the plate.

The second impact test was made on the curved edge of the bottom of the plate. For this test a rectangular hammer having a rounded striking face was used, and the support was tilted so that the force of the impact was directed perpendicular to the tangent of the curve.

Final failure was considered to have occurred in both tests when the enamel was fractured over an area at least $\frac{1}{4}$ -inch in diameter opposite the point of impact.

¹ R. R. Danielson and H. P. Reinecker, "Wet Process Enamels for Cast Iron," *Jour. Amer. Ceram. Soc.*, 5, 667 (1922).

APPARATUS USED IN IMPACT TESTS.

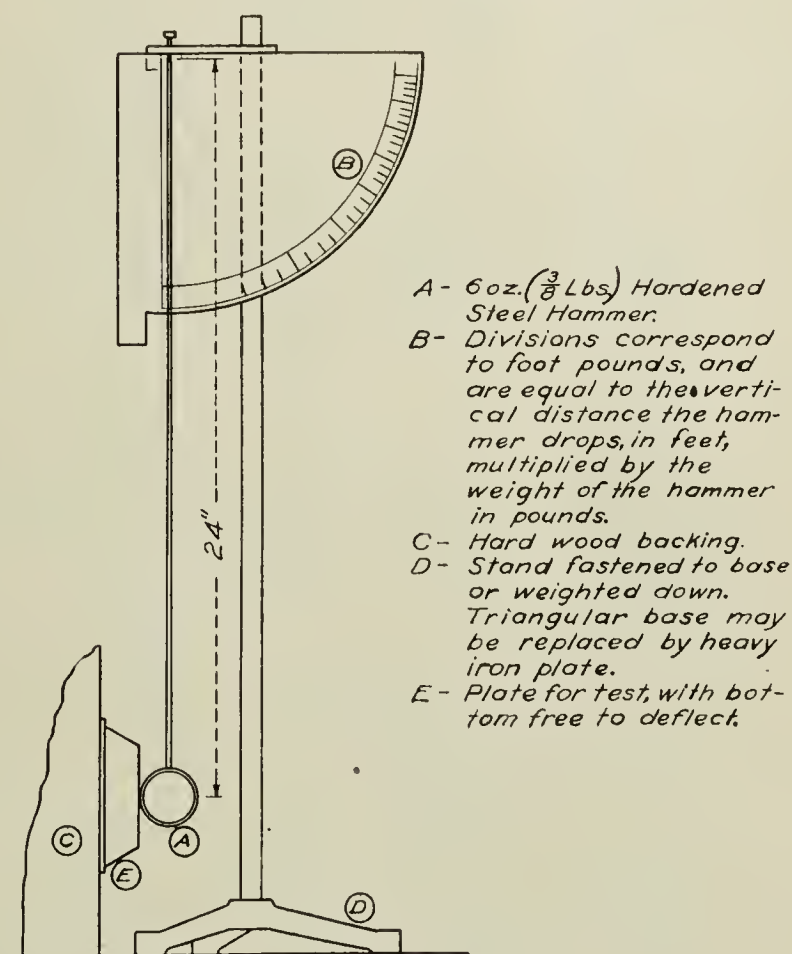


FIG. 7.

Tests were made on four plates for center impact and the same plates were then tested on the curved edge at four points, thus giving an average of sixteen tests in the latter case. It was considered advisable to make the

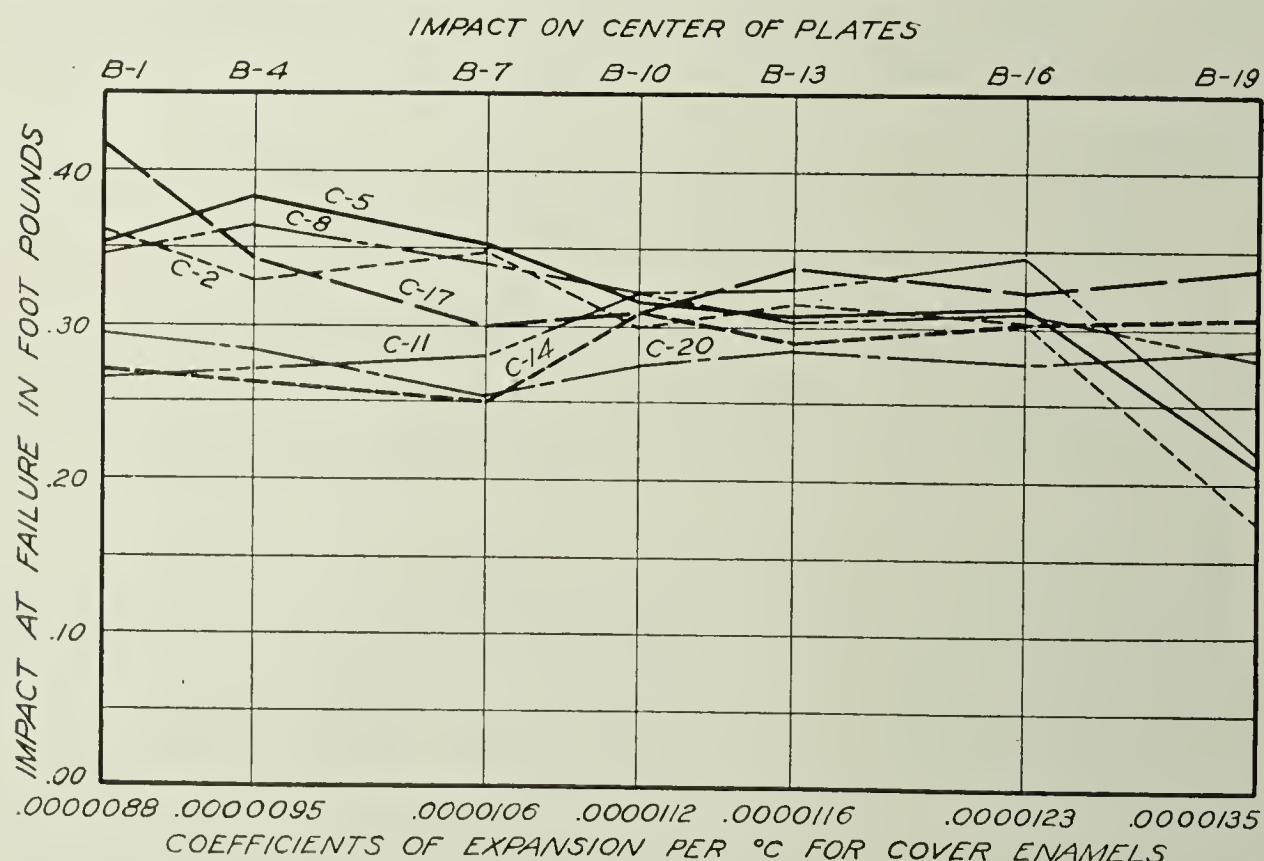


FIG. 8.

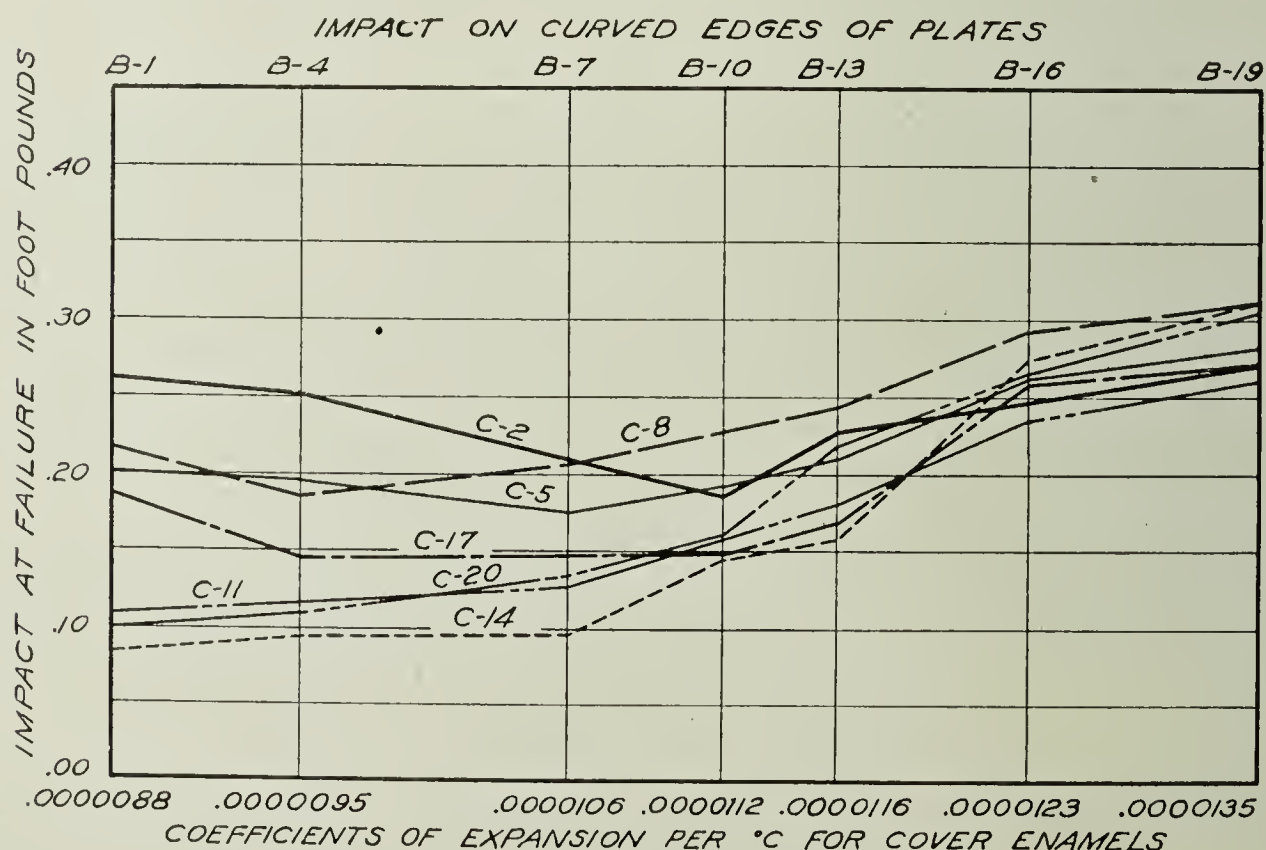


FIG. 9.

large number of tests because of the greater variation in the tests. This variation is undoubtedly due to the tendency for the enamel to chip more readily if struck a glancing blow. With the type of apparatus employed

this cannot always be avoided. However, the large number of tests should compensate for variations in the individual results. The results of all impact tests are given in Tables XIII to XIX. The average values are also shown graphically in Figs. 8 and 9.

TABLE XIII

IMPACT TESTS ON PLATES COATED WITH C-2 GROUND COAT

Cover enamel	Failure at center of plate in foot-pounds			Failure at curved edge in foot-pounds		
	High	Low	Average	High	Low	Average
B-1	0.375	0.325	0.362	0.300	0.200	0.260
B-4	.350	.300	.331	.300	.150	.253
B-7	.400	.300	.350	.300	.175	.207
B-10	.350	.275	.301	.275	.125	.187
B-13	.350	.275	.318	.275	.150	.228
B-16	.375	.275	.306	.325	.150	.248
B-19	.250	.125	.181	.300	.250	.273

TABLE XIV

IMPACT TESTS ON PLATES COATED WITH C-5 GROUND COAT

Cover enamel	Failure at center of plate in foot-pounds			Failure at curved edge in foot-pounds		
	High	Low	Average	High	Low	Average
B-1	0.400	0.325	0.356	0.225	0.200	0.203
B-4	.400	.325	.382	.225	.175	.197
B-7	.375	.350	.355	.200	.150	.179
B-10	.350	.225	.312	.225	.150	.189
B-13	.325	.275	.306	.275	.200	.212
B-16	.350	.300	.312	.225	.125	.268
B-19	.275	.150	.218	.350	.300	.283

TABLE XV

IMPACT TESTS ON PLATES COATED WITH C-8 GROUND COAT

Cover enamel	Failure at center of plate in foot-pounds			Failure at curved edge in foot-pounds		
	High	Low	Average	High	Low	Average
B-1	0.375	0.325	0.344	0.275	0.175	0.218
B-4	.400	.325	.365	.225	.150	.186
B-7	.375	.325	.340	.250	.200	.207
B-10	.375	.250	.315	.225	.150	.190
B-13	.350	.275	.325	.325	.225	.242
B-16	.400	.275	.345	.375	.200	.291
B-19	.250	.150	.220	.325	.275	.310

A study of the results of the impact test at the center of the plates indicates that there is a rather definite relation between the relative expansivity of the ground coat and cover enamels and the resistance of the ware to impact. Since the ware is allowed to deflect freely, it is believed that this test gives a measure of the adherence of the enamel to the steel.

While there are some irregularities in the curves, they are undoubtedly

TABLE XVI

IMPACT TESTS ON PLATES COATED WITH C-11 GROUND COAT

Cover enamel	Failure at center of plate in foot-pounds			Failure at curved edge in foot-pounds		
	High	Low	Average	High	Low	Average
B-1	0.300	0.225	0.265	0.125	0.100	0.111
B-4	.300	.225	.270	.150	.100	.119
B-7	.325	.200	.280	.150	.100	.129
B-10	.350	.300	.320	.200	.125	.156
B-13	.350	.275	.305	.250	.150	.182
B-16	.350	.250	.310	.275	.200	.234
B-19	.325	.200	.280	.275	.200	.262

TABLE XVII

IMPACT TESTS ON ENAMELED PLATES COATED WITH GROUND COAT C-14

Cover enamel	Failure at center of plate in foot-pounds			Failure at curved edge in foot-pounds		
	High	Low	Average	High	Low	Average
B-1	0.300	0.225	0.268	0.100	0.075	0.084
B-4	.300	.225	.265	.125	.075	.094
B-7	.350	.200	.250	.100	.075	.097
B-10	.375	.250	.312	.150	.125	.141
B-13	.325	.250	.290	.175	.125	.157
B-16	.350	.275	.305	.325	.250	.275
B-19	.350	.250	.305	.350	.225	.309

TABLE XVIII

IMPACT TESTS ON ENAMELED PLATES COATED WITH GROUND COAT C-17

Cover enamel	Failure at center of plate in foot-pounds			Failure at curved edge in foot-pounds		
	High	Low	Average	High	Low	Average
B-1	0.525	0.350	0.418	0.225	0.125	0.189
B-4	.425	.300	.345	.175	.125	.148
B-7	.350	.250	.300	.200	.125	.148
B-10	.350	.275	.310	.150	.125	.146
B-13	.375	.300	.337	.125	.100	.165
B-16	.375	.275	.325	.300	.200	.258
B-19	.375	.300	.335	.300	.225	.272

TABLE XIX

IMPACT TESTS ON ENAMELED PLATES COATED WITH GROUND COAT C-20

Cover enamel	Failure at center of plate in foot-pounds			Failure at curved edge in foot-pounds		
	High	Low	Average	High	Low	Average
B-1	0.325	0.275	0.294	0.100	0.075	0.098
B-4	.350	.225	.285	.125	.100	.111
B-7	.325	.225	.255	.175	.100	.132
B-10	.300	.250	.275	.200	.125	.159
B-13	.325	.250	.285	.250	.200	.217
B-16	.300	.250	.275	.300	.250	.260
B-19	.325	.275	.287	.300	.275	.303

due to variations in the preparation of the samples. Such factors as thickness of enamel coating, exact gage of steel, and time and temperature of firing of the ware would have a bearing on the results, and because of the magnitude and character of the investigation, it was impossible to gage these to exactness. However, it may be stated that the ground coats with a low coefficient of expansion develop best adherence to the ware when covered with a cover enamel of low expansivity, the resistance to deflection rapidly decreasing as the coefficient of expansion of the cover enamels becomes relatively higher. With ground coats of a medium coefficient of expansion, best results are obtained with cover enamels of the same expansivity. For ground coats of a high expansivity cover enamels of the same high expansion should be used. It is evident from the general results that for best adherence of the enamel on three coat ware the cover enamel must have the same expansion as the ground coat.

Because of the shape of the plate (see Fig. 5) it is believed that the impact on the curved edge will give a measure of the toughness of the enamel coating itself, rather than a measure of its adherence to the ware. An examination of the curves showing the results of impact on the curved edges, indicates (with the exception of the C-2 ground coat) a definite increase in the strength of the cover enamels with substitutions of boric oxide by sodium oxide. On the other hand, it will be noted that the best results were obtained with the ground coats high in boric oxide.

With increase in sodium oxide these ground coats appeared to decrease in compressive strength, whereas in the cover enamels the strength increased.

The results of the compression tests of the enamel cylinders and the impact test on the curved edges seem to bear some relation to each other. It would appear that the resistance to impact on a curved edge not free to deflect is essentially a question of toughness of the enamel rather than of its adherence to the steel. However, it is assumed that of two enamels having the same inherent properties, the one giving best adherence to the metal will best withstand impact of this type.

THERMAL SHOCK TESTS OF ENAMEL PLATES
Quenching From 175°C. To 28°C.

							C
C-20	50	50	50	50	50	50	50
C-17	50	50	50	④ 13	50	50	C 50
C-14	50	50	50	⑫ 17	⑦ 6	C 20	C 43
C-11	50	50	50	⑧ 6	10	C 22	C 2
C-8	50	50	50	7	18	C 12	C 2
C-5	50	50	50	③ 4	⑥ 15	C 2	C 1
C-2	50	50	50	⑩ 15	④ 39	C 3	C 1
	B-1	B-4	B-7	B-10	B-13	B-16	B-19
	50-No Failure to 50 Tests			C-Enamel Cracked 17-No. of Quenchings for Failure			

FIG. 10.

Resistance of Enameled Plates to Thermal Shock

Two methods of testing the plates for resistance to thermal shock were employed. The first was a quenching test in which the plates were placed in an oven, maintained at a temperature of 175°C (347°F) and allowed to remain 15 minutes, then withdrawn and plunged into water at a temperature of 28°C (82°F). The test was repeated up to 50 quenchings unless failure occurred. The results of the quenching tests are shown in Fig. 10, and these are also shown graphically in comparison with the expansion of the enamels in Fig. 11.

The second method was a boiling test. The plates were so placed on a tripod that they were supported only on the rim. Cold water was then

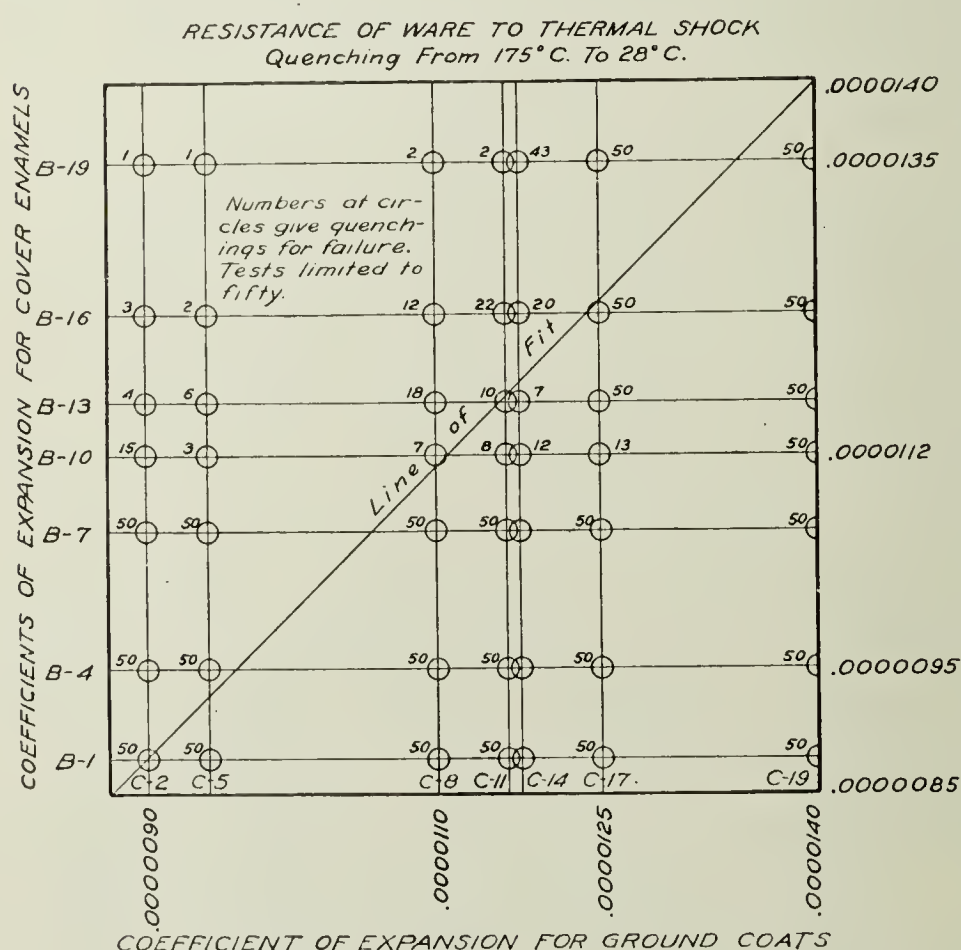


FIG. 11.

placed in them to a depth of one-half inch and a bunsen burner flame placed under the center of the plate. The flame was regulated so that the total flame height was 12 inches with a cone height 4 inches under a gas pressure of about 2.5 inches of water. The water was allowed to come to boiling. The plate was then removed and examined for cracking or chipping of the enamel either being considered as grounds for rejection of the enamel. The test was repeated five times unless failure took place before. The results of the test are shown in Fig. 12 and these have been plotted according to the expansion of the enamels in Fig. 13.

The diagonal line in Figs. 10 and 12 may be designated as the fit line that is, any plate coated with enamel whose coefficients of expansion for ground coat and cover were equal would be placed on this line. Likewise any intersection below this line will represent a plate on which the expansion of the ground coat is higher than that of the cover enamel; and, conversely, any intersection above the line represents a plate on which the ground coat coefficient of expansion is lower than that of the cover enamel.

placed in them to a depth of one-half inch and a bunsen burner flame placed under the center of the plate. The flame was regulated so that the total flame height was 12 inches with a cone height 4 inches under a gas pressure of about 2.5 inches of water. The water was allowed to come to boiling. The plate was then removed and examined for cracking or chipping of the enamel either being considered as grounds for rejection of the

There seems to be very close agreement between the results of the two methods of test for thermal shock. Results of the boiling test as given in Fig. 12 show no complete failure of the ware below the "fit line." One or two enamels close to the line developed fine cracks and it must be remembered that the cover enamels B-16 and B-19 showed pronounced crazing before being tested. All failures in this test developed in enamel combinations above the "fit line," that is, on plates coated with a cover enamel having a higher expansivity than that of the ground coat.

Resistance of the Enameled Plates to Acetic Acid

A one per cent (by volume) acetic acid solution was placed on the plates and then removed at five minute intervals for examination of the enamel.

Cover Enamels B-1 to 10 did not show indications of attack until they

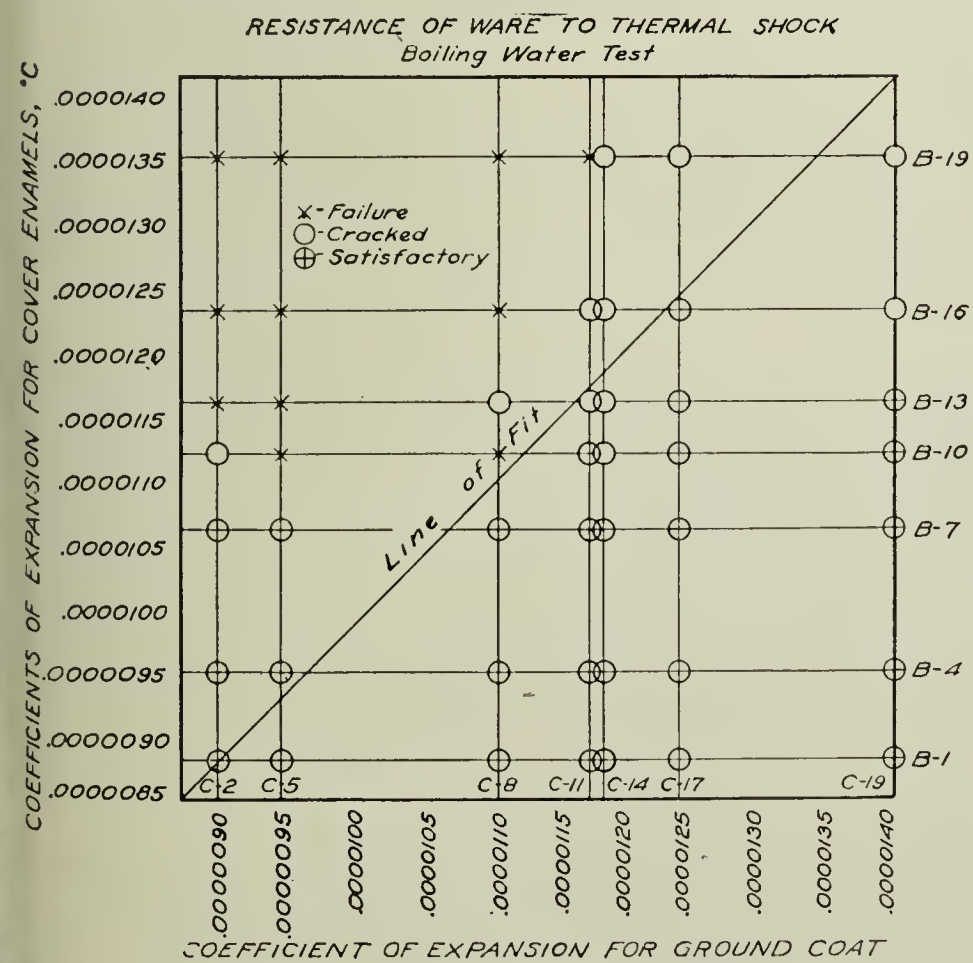


FIG. 13.

RESULTS OF THERMAL SHOCK TESTS
(Boiling Test Of Enameled Plates)

C-20	OK	OK	OK	OK	OK	C	C
C-17	OK	OK	OK	OK	OK	C	C
C-14	OK	OK	OK	C	C	C	C
C-11	OK	OK	OK	OK	C	C	F
C-8	OK	OK	OK	F	C	F	F
C-5	OK	OK	OK	F	F	F	F
C-2	OK	OK	OK	C	F	F	F

B-1 B-4 B-7 B-10 B-13 B-16 B-19
OK-No failure C-Enamel crazed F-Enamel flaked

FIG. 12.

had been tested 20 minutes. They then developed a slight loss of gloss. Enamel B-13, however, showed this same loss of gloss at the end of ten minutes and enamels B-16 and B-19 at the end of five minutes. The action did not extend beyond loss of gloss for enamels B-1 to 13 after 80 minutes' exposure whereas enamels B-16 and 19 showed distinct chalking. It was evident that in this type of

cover enamel the replacement of boric oxide by sodium oxide tended to lower the acid resistance of the enamel.

Conclusions

In presenting the conclusions of this work, it must be borne in mind that the nature of the investigation made it advisable to use a series of enamels not necessarily of a commercial type. However, it is believed that fundamental data on the relations existing between enamel composition and properties of the enamel have been determined.

1. Replacement of boric oxide by sodium oxide increases the coefficient of expansion of these enamels. While this is in accordance with the findings of Mayer and Havas, it is well to emphasize that too much value should not be placed on the calculated coefficient of expansion of the theoretical enamel composition. The latter is apt to vary with time of smelting and other variables so that only very approximate values can be obtained by the use of the Mayer and Havas tables.

2. The compressive strength of these ground coat enamels appeared to decrease with the replacement of boric oxide by sodium oxide, while the reverse was true for the cover enamels. It is evident that effect of variations in composition on the strength of an enamel can only be expressed in terms of a definite enamel composition.

3. Impact on the parts of enameled ware free to deflect appears to give a measure of the adherence of the enamel to the metal. For best adherence a cover coat having the same expansion as the ground coat should be used.

4. Impact on the parts of enameled ware not free to deflect, such as the curved corners at the bottom, gives a measure of the toughness of the enamel. The resistance of the enamel on corners to impact apparently is a function of the inherent strength of the enamel rather than its "fit" on the ware.

5. For greatest resistance to thermal shock, the ware should be coated with a ground coat having a coefficient of expansion equal to or preferably greater than that for the cover enamel.

6. It is apparent from the results of this work, that the effect of sodium and boric oxides on acid resistance varies with the type of enamel under investigation. For these particular cover enamels, resistance to acid decreased with replacements of boric oxide by sodium oxide.

Summary

It is evident that the correction of one defect in an enamel may mean the introduction of others. It is possible in spite of these limitations to develop enamels which are satisfactory for all reasonable service. The

fundamentals established in this investigation, while not based on enamels of a commercial type, will aid those interested in correcting defects of a particular enamel and in developing enamels of more desirable properties.

NOTE: The authors are indebted to W. H. Souder and Peter Hidnert for the expansivity determinations, to C. F. Aitchison for the results of the compression tests, and to T. D. Hartshorn and E. M. Saeger for the vast amount of work involved in the preparation and testing of the enamels. This investigation represents the work of five investigators over a period of about six months, during which time about 300 pounds of enamels were prepared and some 600 dinner plates were enameled and tested, in addition to the miscellaneous tests conducted on the various enamels.

BUREAU OF STANDARDS
WASHINGTON, D. C.

AN ELECTRIC FURNACE FOR VITREOUS ENAMELING¹

BY CARL SCHWIER

ABSTRACT

An electric furnace for vitreous enameling built with round wire coils placed in top, bottom and both sides. The furnace is equipped with a double loading fork and some cost data are given.

The electric furnace has come into the enameling industry and undoubtedly has come to stay. The object of this paper is to show that the type of furnace installed in the Mansfield Vitreous Enameling Co., by the Westinghouse Electric & Manufacturing Co., can be operated successfully and economically except possibly in some remote localities where power facilities are such that interrupted service and cost of power render its use prohibitive. Where the power cost is average, say 1.5 cents per kilowatt hour, the unit cost of ware from the electric furnace will compare favorably with that of an oil-fired clay muffle. In localities where the power cost is low, as in those served by hydro-electric plants, the furnace will produce vitreous enameled ware at a lower cost than will an oil-fired furnace. The cleanliness, compactness and convenience of operation will be apparent after a description of this furnace is given.

This furnace is the heavy duty industrial radiant type, that is, all of the heating elements except those on the bottom are exposed.

The inside dimensions are 48 inches wide, 10 feet 20 inches long, 13 $\frac{1}{2}$ inches high to spring line of arch and 17 $\frac{1}{2}$ inches high to the top of the arch. The type of ware to be burned will, of course, determine these dimensions. Together with the control instruments and panels the furnace requires 169 square feet of floor space. The charging device occupies a floor space of 216 square feet directly in front of the furnace and the fork protrudes from the center of this for 11 feet more. The fork is 26 inches wide.

This furnace is of the brick-buckstay type of construction built up from the floor to the heating chamber with 13 $\frac{1}{2}$ inches of highly efficient insulating brick. The walls are built of similar material and are 16 inches thick to the heating chamber. The roof is made of granular insulating material and is 16 inches thick to the heating chamber. The heating chamber itself is made of 5-inch thick fire brick, the inside of which is corrugated so as to permit the heating coils and coil supports to fit into the wall instead of protruding into the furnace chamber. A vestibule forms the first 20 inches of the chamber and was built in to minimize the door losses. There remains an actual grate area of 40 square feet. The whole furnace is encased in $\frac{1}{4}$ -inch boiler plate and held tight with buckstays. During operation, this boiler plate becomes barely warm so it is evident that the insulation is very effective.

¹ Presented before the Enamel Division, Pittsburgh Meeting, Feb., 1923.

Two weeks were required to build the furnace after all material was on the ground.

The door has a structural steel frame, is filled with insulating brick and is faced on the inside with granular insulating material. It is held snugly against the furnace and being raised and lowered in a perfectly vertical plane by an air cylinder and piston, the dust usually caused by scraping doors is eliminated without sacrificing heat lost by radiation. As the door is very evenly counter-balanced the operator, simply by pressing a lever, can manipulate it with quite the same degree of dexterity as if it were of the old type with the handle. This arrangement minimizes the physical exertion of the workman which makes it highly desirable, particularly in warm weather, because the furnace will average from 18 to 23 loads per hour. When the furnace is idle there is very little heat lost anywhere by radiation and hence the power required to maintain a constant temperature at no load is cut to a minimum.

All of the heating elements are made of No. 1 B & S gage chromel "A" round wire, approximately 80% nickel and 20% chromium, and are coiled so that the strands are one inch apart. The whole coil is 8 inches wide and 5 feet long. There are 24 elements in all: 10 on top, 10 on the bottom and 2 on each side. They are made with butt weld terminals and all are interchangeable. The coils being made of round wire, expose the least surface possible so that oxidation is cut to a minimum.

The terminals are made of 000 B & S gage round wire because by thus increasing their size the current density through the wire passing through the walls is reduced enough to keep the temperature of the terminal well below that of the coil. In this way, too, the heat lost by the terminals passing through the walls is reduced. All terminals are connected by solderless connectors which are protected from contact with workmen by perforated metal guards.

The danger of short circuiting the coils by touching them with ware from the inside of the furnace is eliminated due to the corrugations in the fire-brick lining into which the coils fit. These corrugations act both as reflectors and radiators of the heat as well as insulators.

Small fiber-brick ledges are placed among the coils on the floor and are covered over with close fitting cast plates of non-oxidizing metal so that there is no weight directly on the heating elements. Two long resting bars of the same material as the floor plates, weighing 104 pounds each, are placed from the vestibule to the rear of the furnace to support the racks.

The furnace operates on 60 cycles, 3 phase, 220 volts; voltage regulation being obtained by the use of auto-transformers. Its normal input is 165 kilowatts. The 24 heating coils are divided into two control groups, one of which covers the front half of the furnace and the other, the rear half. The coils are connected as previously described, so that four of

them are in series in each of the three phases. There is a balanced load on each phase. If greatly different types of ware are to be burned, any heat condition required can be obtained by simply changing the voltage through the taps of the auto-transformers. The input in the front group is slightly greater than that in the rear to compensate somewhat for the door losses.

A pyrometer is placed 24 inches behind the door and inserted through the roof and is connected to a controlling recording instrument which controls the temperature of the front group. Another pyrometer is inserted through the rear wall and is connected with a controlling indicating instrument, which controls the temperature of the rear group. A portable recording pyrometer was placed temporarily in the middle of the furnace through the roof so that it was possible to get temperature records of the front, center and rear of the furnace during operation. The instrument in the front group records every two seconds while the one in the center records every 10 seconds. As a result, the absolute temperature changes are shown. These instruments were checked with less sensitive instruments on our oil-fired furnaces with results to be read later. By giving the instruments a little weekly attention, no trouble has been experienced from them.

As we see the problem of obtaining the maximum continuous production there are two choices as to loading equipment. The double end furnace is another choice which will not be considered here. The devices referred to for operating a single end furnace entail the use either of two pronged forks with supporting racks permanently placed in the furnace, or two sets of burning racks and one ordinary fork.

The first device is an arrangement whereby a portable carriage is fitted with two sets of tracks similar to those ordinarily used for a single fork. On each of these tracks is mounted a fork with some six or eight prongs about 4 inches apart and fitted with low points. The number of prongs and their spacing depend on the size of the furnace and the type of ware to be run. Inside the furnace there are as many resting bars plus one, as there are prongs on the fork, and they are spaced the same. These run the depth of the furnace and are also fitted with short points. In operation, ware is placed on the fork prongs of one fork, is inserted into the furnace, dropped on the pointed resting bars, and the fork is removed. As soon as one load is finished it is taken out and moved, fork and all, to one side, thus bringing the loaded second fork to the door opening. The first fork is unloaded and loaded again and is ready to go back into the furnace as soon as No. 2 comes out. This arrangement is ideal for large ware or any ware where there is no danger of losing pieces between the prong spaces. It can be used for small ware by simply placing the ordinary burning racks on each fork. In this way maximum production can be obtained on small ware as well as large ware at the expense of keeping a

set of racks continually in the fire. When no burning racks are used the number of heats per hour is obviously increased and on account of the decreased heat demand thus effected, a better temperature can be maintained at a lesser power consumption. If there is, however, any considerable warpage of the racks due to temperature changes when the door is opened, the prongs may not fit and production is stopped until they are straightened. This detail could undoubtedly be overcome by making the resting bars of sections about 2 feet long. The carriage supporting the forks may operate either on the floor or on tracks overhead.

The second device is the one in use in our plant. It consists of two sets of tracks mounted on a carriage which moves back and forth on floor tracks in front of the furnace. These tracks on the carriage each support a set of the usual burning racks consisting of five links and six to eight rows of points. One fork is used. As one set of racks is loaded it is moved in front of the furnace door, the fork is raised, the load inserted, and the fork is lowered and withdrawn. The two resting bars previously mentioned in the furnaces are sufficient to support the racks. When that load is burned, it is withdrawn and moved to one side while the other one is inserted. This alternately loading and heating arrangement affords continuous operation with only a few seconds loss between heats. The ware may be so small as to require the full heating interval for unloading and reloading without reducing the square feet per hour produced. The defects of this system are: (a) Whereas excellent production can be maintained on small ware, the number of loads per hour on large pieces is not much greater. (b) Considerable heat is lost from racks by radiation resulting in a great heat requirement from the furnace at each load. (c) The fork is a little slower than those on our oil-fired furnaces.

This system requires three men to work it and averages 50% more production than our best oil-fired furnace. We are installing brakes for the fork and carriage and so expect to speed the fork operation considerably. Our work consists chiefly of stove parts and, therefore, a large percentage of it is small ware. All of it must be well supported on account of the subsequent assembling. For this reason, we are necessarily carrying a considerable weight of rack and are asking the furnace to raise the temperature of these racks some 500° at each heat. It will be seen then, that the type of ware to be burned will determine largely the type of loading apparatus.

Operation data will be given in kilowatt hours and percentages rather than in money per unit work because different localities have different power rates and because we feel that a longer period of operation than that over which our data was taken is necessary to obtain accurate data on maintenance, depreciation, and other such items which must be considered in the ultimate cost calculation.

Our electric furnace of 40 square feet grate area gave us 60% more production than did an oil fired clay muffle of 39 square feet grate area. These furnaces burned the same type of ware throughout the month and their production was based on square feet per working hour. During this period the oil furnace lost $4\frac{3}{4}$ hours waiting for proper heat and the electric furnace lost $\frac{3}{4}$ hour when a blown fuse went unnoticed long enough to allow the temperature to be pulled down. Accurate temperature control was possible at all times as will be shown by the recording chart.

The average power consumption per hour was 114 kilowatt hours. A power factor correction estimated at 15% will be allowed us as soon as the power factor is accurately determined. Weight of racks per heat was $126\frac{1}{2}$ pounds to $159\frac{1}{2}$ pounds depending on the type of ware burned. Loads per hour ranged from 18 to 23 also depending on the gage and type of ware burned. A ten second recording instrument actuated by a thermocouple in the rear of the furnace showed a 10° greater variation each heat in the oil furnace than in the electric furnace on identical ware. The temperature variation two feet in rear of the electric furnace door was 80° . This data on the oil furnace will be available as soon as we receive a porcelain protecting tube so that a thermocouple may be inserted through the heating chamber into the muffle at this point.

In lighting off each week after our usual week-end shutdown, it is our practice to have a man come in ten hours previous to the time when the furnace is to go to work. During this time he lights the burners, fires the boiler which heats the oil and sees that all auxiliary equipment runs smoothly. He receives time and a half pay on Sundays. Three hours before the electric furnace is to go to work he pushes two buttons on it and then resumes his other work. No labor can be charged to the electric furnace for lighting off. The furnace is so well insulated that the temperature falls barely 350 degrees in 24 hours. It responds so quickly then that only 30 to 45 minutes are required to raise the temperature 500° . We allow our furnace to saturate at 1700°F for the balance of three hours so that its walls become thoroughly heated and it is easier to maintain a desired temperature. The power required during a three hour lighting off period after a shutdown of 21 hours averaged 210 kilowatt hours. After the furnace becomes saturated, only 17.2 kilowatt hours per hour are required to maintain a temperature of 1600° and 18.3 kilowatt hours per hour to maintain a temperature of 1700° . This data was taken over periods of at least 12 hours.

We have found that the quality of ware produced by the electric furnace is of the highest, due to absence of gases and to accurate temperature control. The furnace has given us a high production per unit floor space of burning department and has given us this production without interruption. Our maintenance crew has not touched it except to replace

two or three fuses. At a power cost of 1.46 cents per kilowatt hour our unit cost of production has remained the same as when only oil fired furnaces were used with oil at $6\frac{1}{4}$ cents per gallon.

MANSFIELD, OHIO

Discussion

C. SCHWIER:—Power is wholesaled on a sliding scale depending on the quantity consumed, that is, the more power used, the less is the unit cost. As our plant is purely an enameling plant, the total power consumed even with the electric furnace, is relatively small, thus putting us in the highest charge class and making our cost per kilowatt hour $1\frac{1}{2}$ cents.

B. T. SWEELY (Chairman):—Do I understand that there are coils in the arch as well as in the floor?

C. SCHWIER:—Yes.

F. G. JAEGER:—How much space is required for trackage on each side of the furnace?

C. SCHWIER:—About four feet.

F. G. JAEGER:—Operators unload from both sides?

C. SCHWIER:—Yes. The space for unloading is about four feet wider than on an ordinary furnace.

B. T. SWEELY:—What were the degrees of temperature indicated on the chart?

C. SCHWIER:—This was 1600°F and this variation 100°F . The drop in temperature seldom was more than 100°F .

B. T. SWEELY:—Was this taken in the crown of the furnace?

C. SCHWIER:—This was taken in the center of the crown about two feet from the door.

R. D. WELLS:—I should like to ask Mr. Schwier if he has any chart showing the power input. I understand input while the power heating up the furnace is 120 kw. What is the power input when a new load has been put in?

C. SCHWIER:—This cannot be calculated at every heat because a load may be inserted and withdrawn without throwing in both contacts when enough stored heat is present to burn the ware. We take our data over a period of an hour in order to compensate for full load and no load periods in the furnace operation. The maximum load obtainable is 157 kilowatt hours.

R. D. WELLS:—When either of your contacts is out?

C. SCHWIER:—If both contacts are in, the consumption is 157 kilowatt hours. If one is out, the consumption is only half that.

V. A. HAIN:—That brings up a very important point in proper electric furnace operation. All electric furnaces are designed to take care of certain production per hour, figured in either square feet per hour or pounds

per hour. That is, the furnace is equipped with electric heating elements of sufficient capacity to heat the tonnage specified to the temperature specified in the time specified.

The furnace is equipped with automatic temperature control, so that in case a smaller amount of work is to be put through the furnace less power would be required to do the heating; the automatic temperature control automatically allows just the right amount of electrical energy to go into the furnace to raise this quantity of work to the proper temperature, which means that the current is off of the furnace a portion of the time when the furnace is handling less than full load.

Any piece of apparatus is working at its maximum efficiency when it is operating the full load for which it is designed—in the operation of electric furnaces this is particularly true on account of the fact that one of the factors which determines the cost of current is the percentage of the time that the current is on the furnace, compared to the total time that the furnace is in operation, the lowest rate being obtained when the current is on the furnace 100% of the time. So, the more efficient operation for an electric furnace is to load it so heavily that the current is never automatically thrown off.

C. SCHWIER:—Regardless of how the furnace is hooked up it will, at some periods of the month, require a maximum temperature and a maximum power input. The demand charge would be the same in either case because it is calculated from the peak load for a fifteen minute period.

H. H. CLARK:—Do you know what the power consumed per square foot will be?

V. A. HAIN:—It is very unwise to make a general economy statement, not only on an electric furnace, but on any other kind of a furnace; such as kilowatt hours consumed per square foot or the kilowatt hours consumed per pound of material passing through it.

This figure changes with every furnace installation and the only logical position to take on a question of this kind is that this figure must be obtained for any particular furnace installation when the various conditions which go to make up this economy figure are known, such as the size of the furnace, the amount of work passing through it, the temperature to which it is held, etc. Any general figure of this kind is always misleading, and should not be given.

C. SCHWIER:—I gave you our figures at the time the ware was burned.

V. A. HAIN:—The figure which you gave could be very easily misinterpreted, unless full explanations accompanied it, giving the furnace operation upon which it was obtained. A general economy such as this could not be universally applied to any class of work.

F. S. ROBERTS:—What is the actual cost of running a furnace at 1500° on eighteen-gage iron?

C. SCHWIER:—I cannot give that figure because we have not run much 18-gage ware in the electric furnace.

W. R. GREER:—Can you increase your heat immediately by increasing the kilowatt input or must you allow the furnace to stand idle in order to allow the heat to soak up to required temperature?

C. SCHWIER:—If we were running finished ware and wanted to burn ground coat immediately, more energy would be required. We can raise the temperature while burning by changing the input at the autotransformer.

L. W. MANION:—I think we are all familiar with the class of work done in this field. I believe there has been a bill rendered. Mr. Schwier has taken a twenty-four hour period. I should like to know what the cost would be in two weeks or a month.

C. SCHWIER:—We are so situated that we have to pay the high rate, $1\frac{1}{2}$ cents per kilowatt hour. Based on 475 square feet per hour production, we produced about three square feet per kilowatt hour. The production was about 240,000 square feet on that furnace per month.

L. W. MANION:—I am not very familiar with electricity. What is the actual cost? How much money did it cost you?

C. SCHWIER:—You multiply 157 by 24 by the number of days in the month and you get the maximum power consumption in kilowatt hours. Multiply this by .0150 to get cost when operating at continuous full load.

The maximum demand is shown on our bill as 140 kilowatt hours. I am taking 600 hours as the time during which the furnace was in operation during the month. I multiply these by 157, the hourly power consumption and then by .0146 and our bill will be \$1,224.00 for 240,000 sq. ft. A great saving is made in the cost of lighting off. Based on fuel per square foot the oil furnace will be considerably less than the cost of operating this furnace. Other expenses compensate for this difference, however. The reason I did not give actual dollars and cents figures was that I did not use the lighting off and other maintenance data.

F. G. ROBERTS:—This gives an average of .0148 per square foot.

B. T. SWEELY:—This gives us about $\frac{1}{2}$ of a cent a foot for fuel cost. This was divided by three to get each cost.

R. E. ARNOLD:—Where do you take the temperature measure?

C. SCHWIER:—We set two groups of instruments, one at the front end and one at the rear. We have a thermocouple two feet from the door of the furnace and another at the rear. They record every two seconds. We also had one in the center of the furnace that recorded every ten seconds, so we had a record of the absolute temperature changes.

V. A. HAIN:—Temperature charts such as you have seen are of very great value to enable an operator to analyze the working of his furnace equipment, as from it such items as lost time, loading time, burning time,

etc., can be quickly and accurately determined, and from such a chart the production of a burning crew can be held up to a high figure.

On the other hand such a chart may be the cause of misapprehension particularly if the temperatures indicated are taken to mean furnace temperatures. Whether or not the indications on these meters are furnace temperatures depends on where the thermocouple is located. At the inside wall of the furnace it will indicate closer to furnace temperature than if the thermocouple is extended well into the chamber of the furnace, because in this latter case the thermocouple is near the cold work as it is introduced, and the temperature which the instrument reads is always the temperature at the end of the thermocouple, which would be considerably lower than furnace temperature immediately after the introduction of cold work.

H. H. CLARK:—As I understand it the cost is fifty cents each hundred feet, or three times your figure (.14 plus) for one coat.

MR. FREEMAN:—How does that compare with your oil furnace?

C. SCHWIER:—For an oil furnace we burn about 250 sq. ft. per hour at a cost of .0025 per sq. ft. for fuel only.

R. TURK:—What is the cost of this furnace?

C. SCHWIER:—The cost, including the transformer, is about \$9,000.

B. T. SWEELY:—Did your figures include the furnace overhead? Are those figures what it actually would cost, or is there still a furnace overhead?

C. SCHWIER:—The overhead of the furnace during the time we have worked it, is practically nothing.

B. T. SWEELY:—Would it be fair to compare the two fuel costs?

C. SCHWIER:—It would not.

B. T. SWEELY:—In other words, in the oil furnace you must add the cost of the furnace overhead, but in the electric you do not.

C. SCHWIER:—That is right.

H. F. STALEY:—According to my figures it costs 86 cents for one coat. Our figures on an oil furnace are about one dollar per day, that is about \$300 per year.

B. T. SWEELY:—Mr. Roadhouse, was this your figure on the intermittent furnace?

R. ROADHOUSE:—I do not think our furnace overhead would amount to \$300 in three years.

H. F. STALEY:—How much did you estimate your upkeep on muffle furnaces?

R. ROADHOUSE:—About \$500 per year upkeep.

H. F. STALEY:—In other words, we must add twenty-one cents per square foot for upkeep. I am allowing \$500 a year to keep up a clear muffler. But you lose some time.

L. D. BRIDGE:—Those things go to pieces in a short period of time.

C. SCHWIER:—Mr. Manion relined the clay muffle used in my compar-

ison on June 8, 1922. On January 15, 1923 we had to put in a new bottom with carborundum piers. This work alone cost more than \$500. In our overhead we must count the cost of operating oil auxiliaries, cost of oil storage, cost of lighting off furnaces and general maintenance to say nothing of the ten days production lost while rebuilding the muffle.

R. A. WEAVER:—I visited an installation of a furnace at Shakopee. They have a Hagan electric furnace. Their power cost the second month was slightly over \$2,000. They were highly pleased with the work, but they felt that the cost was too high. I was talking with a gentleman who has a muffle furnace who was buying his power.

V. A. HAIN:—I am very familiar with the Shakopee installation, and I know any figures obtained at this time are not fair indications of electric furnace operation. In the first place this one electric furnace, at the present time is doing the work of two combustion muffle furnaces, and the electric furnace is only being worked at a fraction of its capacity. It could easily turn out over double its present tonnage.

The operating cost of this furnace, which you have just heard is based on current at a very high rate for electric furnace operation, namely—3.8 cents per kilowatt hour. The user and the power company are negotiating at the present time for a reduction of rate on this furnace but aside from this, the cost of operation of this furnace is very comparable to the cost of muffle fired furnaces when figured on a tonnage basis.

MR. SCOTT:—I do not know about the operating cost of furnaces, but I do know about the principles of electric power cost. In any industrial plant where electric power is used, the power depends upon two figures, the actual energy consumed and the kilowatt demand of the apparatus. Whether or not they are doing any producing they have a demand charge to pay. Obviously if they have a very low production, the direct charge becomes very high in comparison with other forms of power. In the use of electric furnaces or electric motors they should be operated at somewhere near their full capacity in order to get the full value of the power in production.

R. E. ARNOLD:—Would it be possible to apply the same control as in a gas-fired furnace?

C. SCHWIER:—I do not see why it could not be.

R. E. ARNOLD:—Have you or any one else done any work in that line?

C. SCHWIER:—It is done on low temperature japanning ovens.

Mr. Clark, can any other fuel than gas be used in intermittent gas-fired furnace?

H. H. CLARK:—No.

C. SCHWIER:—Then in the majority of smaller towns and even in Cleveland where a constant year round supply of gas is not guaranteed, such an installation would be highly impracticable or at best a gamble.

GLASS DECORATORS' PALETTE AND ITS PREPARATION

BY THEODORE LENCHNER

Introduction

Glass may be decorated by use of a color palette or by cutting, etching, engraving or chipping. Low cost glass wares are sometimes decorated with oil paints, the coloring being organic and the decoration not fixed by firing. We will take up only the color palette of glass decorators made with inorganic colors and fixed by firing.

The decorators' coloring materials may be classified into vitrifiable colors (transparent and opaque), stains, gilding and lusters.

Although the materials and methods used in overglaze decorating of pottery and porcelain are similar to those used on glass, the decorating of pottery will not be considered in this series.¹

Vitrifiable Colors

The manufacture of vitrifiable colors is a highly developed art, especially in foreign countries. In this country their manufacture is comparatively new, but much progress has been made due to the development in chemical science and the increasing control of the raw materials. In fact, certain types of colors manufactured here are superior to those manufactured abroad.

Composition and Preparation

Vitrifiable colors for either glass or pottery are composed of two distinctive parts: the colorant and the flux. The colorant, because of the protracted firing to which these colors must be subjected, consists largely of calcines of metallic oxides, or salts of metals, with clay, flint, zinc, oxide or other non-coloring materials. A typical formula of such a stain is 50% alumina, 5% zinc oxide and 45% cobalt. The flux is an easily fusible glass such as

60 parts Red Lead
30 parts Boric Acid
10 parts Silica.

¹ Considerable training and experience is necessary to qualify as a master decorator, and in this country too few have taken up this work. It is hoped that in the near future, through the untiring efforts of the Art Division of the AMERICAN CERAMIC SOCIETY, a keener interest will be created in the artistic and decorative development of our ceramic products, and the writer believes wonderful work is being done along this line. When that interest is developed, we shall have many more decorators, not only capable of applying these colors, but also creating designs with greater artistic expression, and this in turn will develop the greater use of vitrifiable colors.

This is thoroughly melted in a crucible and poured into water; then finally ground in a pebble mill. Besides being the medium for fusing the colorant to the glass, the flux assists through chemical influence in producing different colors and tints with the same colorant.

A great variety of fluxes are made, their composition depending upon the character of the colorant to be used, the degree of fusibility desired, and the ratio of contraction and expansion of the glass ware upon which the colors are to be fired.

In the manufacture of the highest grade of colors, the color stain and flux are fused or melted together. These melts are then very carefully ground with water or oil to a very fine or impalpable mass.

In some cases the color stain and flux are merely mechanically mixed by grinding together.

Shades or tints of colors can be produced in a variety of ways. The ancients were experts in mixing colors, for the ancient decorative glass wares which have been unearthed show a variety and wealth of color, some of which have not been reproduced.

The physical properties of these fluxes are not materially affected by the added colorant, owing to the small amount of stain added. The color produced, however, depends largely on the composition of the flux and atmospheric condition of the furnace.

The metals employed to produce specific colors are as follows:

Cobalt.....	Blues-Purples
Copper.....	Green-Turquoise-Red
Iron.....	Browns-Blacks-Reds
Manganese.....	Blacks-Violets
Chromium.....	Greens-Oranges-Yellows
Nickel.....	Grays-Browns
Uranium.....	Yellows
Antimony.....	Reds-Oranges
Titanium.....	Cream
Silver.....	Yellows-Amber
Gold.....	Pinks-Reds.

Opaqueness may be increased or decreased by varying the percentage of colorant used, or by using white or translucent flux. The so-called matt (dull) colors may be obtained by the use of a more refractory flux.

Enamels

Other types of vitrifiable colors used in glass decorating besides the regular decorative color palette are enamels, ices, stains, gold and silver preparations, and lusters.

Enamels contain certain amounts of opacifying chemicals, such as tin and zinc, a typical formula for which would be as follows:

60 parts Red Lead	30 parts Silica
20 parts Fused Borax	15 parts Zinc Oxide.

They are treated same as a flux.

The white enamel is most commonly used in decorating lighting goods glass ware, where a translucent or nearly opaque effect is desired. The thickness with which these enamels are applied determines the degree of opaqueness. The enamels are also used with a colorant where a relief decoration is required.

Ices

Ices are vitrifiable colors which, instead of being finely ground in a mill, are subject to a crushing process after which they are graded into different sizes of particles. Ices produce a very interesting rough surface effect. This type of decoration was formerly much used in lighting goods, but is now being used in decorating tumblers.

Application

The colors used on glass are fused onto the glass surface, thus becoming in most cases a permanent part of the glass itself. The "fixing" or fusion of these colors to glass surfaces is accomplished by firing to temperatures ranging from 580°C to 650°C depending upon the nature of the glass and color.

The colors are applied by painting, or by spraying with an air machine especially constructed for this work. These processes have largely replaced the old groundlaying process which consisted of an application of finely powdered color to a slightly "tacky" oil ground.

These colors are first thoroughly ground with turpentine in a paint mill to a consistency of cream, or until the color will just stand up. They may also be ground in a pebble mill. A small amount of a slow drying oil, such as Dresden oil or fat oil of turpentine is added in order that the color will not dry too quickly.

After application the color is allowed to dry and the ware is then placed in the kiln. The temperature is gradually increased; or if fired in a leer, the articles are very slowly moved forward toward the center of the leer where the temperature is the highest.

Stains

Stains differ from the colors in that no flux is required. These are salts of metals. Instead of being used with the flux, they are mixed with ocher or clay and fired in the ordinary way. These metallic salts impart to the glass their characteristic color in a very clear transparent film.

The writer has knowledge of only two metals whose salts are capable of being reduced: Silver, giving the amber or orange stain, and copper, giving the red or ruby stain. This type of decoration under reducing conditions is very difficult to produce. A typical mixture used is 3 parts

calcined yellow ocher and 1 part silver nitrate, thoroughly mixed in a pebble mill. After firing, the ocher may be washed off and the glass underneath will be stained amber.

Effects usually obtained by reduction, which include all the luster decorations (the red or green of copper, green and yellow of chrome, etc.), are hard to control.

Gilding

The metallic gold, silver and platinum decorations are the oldest and most used decorative materials. Their manufacture is quite an art and is successfully practiced by very few concerns. The pure metal is used in powdered form mechanically incorporated with a suitable flux and organic oils and are thus sold in the form of liquid or paste. These preparations are then applied and fired under much the same conditions as the vitrifiable colors.

A liquid, bright gold can be prepared as follows:

5 parts Lavender Oil
5 parts Turpentine

1 part Flowers of Sulphur.

This is boiled over a sand bath for about $1\frac{1}{2}$ hour (according to an old formula). To 8 parts of this thick emulsion is added a solution of gold chloride, which contains one part c. p. gold. This is thoroughly ground together in a mortar with the addition of a small amount of lavender oil. The whole is allowed to stand 24 hours. To this mixture in the mortar is added bismuth subnitrate, equivalent to one-half the weight of gold, and again thoroughly mixed and allowed to stand. This is then taken up in carbon bisulphide, if too thick, and filtered. The whole is allowed to stand on a warm place for 12 hours, after which the solution is ready for application.

Lusters

Lusters may be classified as metallic resins. These are manufactured by slowly adding the metallic salts to boiling mixtures of soluble oils and resins and are thus sold in liquid form. The iridescent effects which impart their characteristic metallic color to the glass surface are not permanent, inasmuch as these lusters do not contain flux, and therefore are not capable of being fused into the glass. Typical yellow luster consists of

1 part Uranium Acetate
3 parts Rosin

5 parts Lavender Oil.

AUTOMATIC KILN STOKERS

BY JOHN D. MARTIN

Introduction

For kiln purposes more heat can be purchased per dollar in coal than in any other fuel. In spite of the generally wasteful methods employed the value of coal as a kiln fuel is proven by its wide use. No fuel without genuine merit could have survived such industrial punishment.

It is burned either as run of mine, or screened; mixed with a bituminous binder and briquetted; gasified in a producer; coked or pulverized and used in form of powder. This discussion is directed to a consideration of fuel and the method of its use in periodical kilns.

Coking and briquetting are too expensive. Their use is justified only under very special conditions.

Pulverized fuel requires intricate and expensive changes in the kiln construction to trap and discharge the ash. If blown into the kiln the ash would collect and interfere with the draft.

Producer gas for periodic kiln burning is a mistake if better economy and same ease of control can be obtained by others means. Gas makes a fine fuel, but unfortunately, this is not the whole story. Before the gas can be burned, not less than 20% of the heat value of the coal has been lost and this loss may be as high as 29% depending on the amount of sensible heat lost between the producer and the kiln. This unavoidable loss certainly places a great handicap on producer gas in comparison with other modern methods of burning raw coal in periodic kilns.

The process of turning a fuel into gas in a producer is not in itself unique. The first stage in burning solid fuel in the kiln firebox is production of gas and the second stage is oxidation of this gas. The coal is gasified in a kiln firebox and the gas burned in the kiln without loss of any of its sensible heat.

The largest obtainable economies are had where the fuel and air supplies and the ash discharge are properly regulated. Such regulation cannot be obtained in a hand-fired furnace.

Coal is used in all its prepared sizes from slack or screenings to lump. It is burned in furnaces of every shape and size with or without specially constructed arches; with flat grates, sloping grates and no grates at all; with means of supplying secondary air from every conceivable part of the furnace, or without any such means; with fire doors, and without; with natural draft, forced draft or induced draft. If a solution of this problem has not been found, it is not because all the possible combinations of these have not been tried, and yet, one authority states that the question of kiln furnaces is one on which the gods themselves cannot agree. We would have been much nearer the solution if it had not been for the fire-

man with his coal shovel. This combination can defeat, and invariably does defeat, all efforts for economy in furnace design to burn raw coal.

The fireman, too frequently, overloads the fireboxes with green coal after having allowed the fuel bed to so burn down as to show sometimes 600% excess air. Such a practice results first in loss of heat carried away by the excess air, and then by incomplete oxidation of the carbon monoxide. He will shovel out ashes which contain too much combustible. In some cases as much as 25% of the heating value of our coal is carted to the ash dump. Poor management of the firing increases unduly the length of time of firing causing slow turnover of kilns, delayed deliveries and a waste of labor and fuel, which is costing the clay working industry unnecessarily untold thousands of dollars per year.

Uniform Stoking Needed

The solution of the problem of burning raw coal in periodic kilns is in employing a means of feeding the coal either constantly or at very short intervals and removing the ashes at the same rate. There should be steady flow of coal in, and a flow of ashes out. Combustion in the firebox is a continuous matter, and it can be maintained most efficiently only within a very short range of variation in condition of the fuel bed. The only practical way to accomplish this is by some form of mechanical stoker, and for kilns this will require a specially designed one.

Stokers for boilers and heating furnaces have been had from the time such furnaces first made their appearance. The early purpose of mechanical feeders was eliminating the smoke nuisance. Three general types have been developed; chain grate, overfeed and underfeed types.

Chain Grate Stoker.—The chain grate stoker consists of a movable grate made up in the form of a flexible chain. It carries green coal into the firebox and discharges the ash at the rear end. It has always been operated by natural draft although some late developments use forced draft.

Overfeed Stoker.—The overfeed type is of two different kinds, one in which the coal is thrown by mechanical means and spread uniformly over the fire, the ashes being dumped through the grate. The other form introduces the fuel at the highest end of a sloping grate and gradually works it to the discharge end by a reciprocating or oscillating motion of the grate bars, and the ashes are discharged by a dump plate, auger or rotary clinker grinder. The larger types of this variety are power driven, but the smaller sizes are operated by hand. The coal may be fed by power and the ashes dumped by hand. With hand manipulation there will be difficulty in keeping the fuel bed in a uniform condition owing to the periodicity of attention given to it. All hand stokers have to be designed with a view of making the intervals between firing and dumping as long

as possible, which is distinctly a compromise in the design to make it easier for the fireman at the expense of the efficiency of the stoker.

The Underfeed Stoker.—The underfeed type of stoker delivers the coal upward through the fuel bed from the bottom, pushing the partially burned coal and the ash toward the point of discharge of the ash. In some designs the movement of the partially burned coal is by the reciprocating grate bars employed in overfeeding. This kind of stoker in recent years has found great favor in central power stations because of its ability to handle a variety of different coals and to force the boilers for long periods at high ratings, in some cases as high as 300% of the normal rating of the boiler. Underfeeding is no doubt the most correct method because the burning fuel is on top of the green coal and the gases from the green coal, mixed with air, pass through the hottest part of the fire. This type will produce a minimum amount of smoke. It is usually operated with forced draft.

Applications of Stoker to Periodic Kiln

A little over two years ago, at the plant of the Straitsville Impervious Brick Company, at New Straitsville, Ohio, experiments were made in burning clear face brick with a forced draft installation. While the burning time was reduced and fuel saved, these savings were eaten up in the additional labor required to hand fire the furnaces to maintain an oxidizing condition. This, however, we were not able to do, as we flashed our brick in spite of all our efforts to prevent it. This led us to believe that a stoker operating with forced draft would overcome this trouble and give us a maximum of economy not only of coal, but of labor.

As there were no stokers on the market made especially for this work, or which seemed well suited for it, we designed a stoker of the size so that one of them could be installed at each firebox of the kiln. We chose the underfeed type as being best suited to carry out our ideas of what a kiln stoker should be. We could have tried a much easier stoker to design, that is, some means of dumping or throwing the coal onto the fire and advancing it to the ash pit either mechanically or by hand, and dumping the ashes by hand, but we did not believe, and do not now, that such a stoker can secure the results which can be obtained by both feeding the fuel and discharging the ashes automatically.

It took over two years to bring our stoker to a satisfactory conclusion and we are convinced that we now have a machine which is capable of wonderful results. I dislike to make such a statement, however, without being able to give the figures of careful tests to prove it, but all ten of the stokers on this kiln have not yet been equipped so as to be in their final form and we have therefore been unable to make final tests of what we will eventually accomplish.

Requirements in Stoker Design

It is apparent that stoker burning will be given considerable attention in the future. It is a new thing now and naturally our industry knows very little about the details of stoker construction. I would like to point out those features in a stoker, the presence or absence of which will mean good, bad or indifferent results.

Forced Draft.—The stoker should be designed for the use of forced draft which, on account of the increased circulation, will drive the heat quicker to the bottom of the kilns. This will speed up all the various periods of the burn, especially watersmoking, during which time it will reduce condensation on the ware in the bottom of the kiln. The intensity of the draft should not be carried to the point of materially increasing the stack temperatures. We have found by using a balanced draft in the kiln that the stack temperature is not materially increased after applying forced draft.

Forced draft will increase the amount of coal which can be burned per square foot of grate area. As a result, the size of the stoker grate and furnace can be reduced and still burn an increased amount of coal per firebox. The burning of more coal per square foot of area with forced draft is important because it results in a hotter fire and higher temperatures of the products of combustion. This means quicker burns provided the ware will stand it, with smaller stack and radiation losses.

We have found that our ware will stand a considerable speeding in firing. In one case, after watersmoking and oxidation, we found it necessary to stop firing and make some changes, during which time the kiln entirely cooled off. We then started burning again and completed the burn with the stokers in 2 days and 20 hours, putting down cone 3 in the bottom. The brick were not damaged in the least by such a rapid rise in the temperature. Our usual burning time with hand fired furnaces is a little over 8 days.

Construction Should Be Rugged.—The stoker and all driving mechanism should be rugged in construction. There should be break pins installed somewhere in the driving mechanism which will relieve the stoker of unusual strains caused by the presence of tramp iron or pieces of brick in the coal.

The stoker should be able to discharge the ashes automatically, and this should be as continuous as the feeding of the coal into the furnace. This is necessary if we are always to keep the fuel bed in the same condition. If we do this there is no reason why we cannot obtain the same steady application of heat which we attain when we fire with gas.

Coal and Ashes Should Not Mix.—The stoker should make a minimum of clinker formation in the fuel bed and on the furnace walls. Usually it is necessary to reach a temperature in the firebox which will fuse the ash.

Fused ash, however, does not of necessity make a hard clinker, but it will be turned into hard clinker by excess of heat and agitation. The more heat and agitation, the larger will be the clinkers.

It is because the ash is subjected to the heat of burning coal that it becomes fused. Burning coal and ashes should never be mixed together in a fuel bed, but if this should happen, the mass should be agitated just as little as possible. To prevent bad clinkers from adhering to the furnace walls, do not mix burning coal and ashes together and agitate the mass along the wall. A well designed stoker will not mix green coal and ashes together, neither will it require hand manipulation of the fuel bed, nor the use of bars or hooks to remove clinker formations from the furnace walls.

Stoker Should Be Designed to Burn Fine Coal.—The stoker should be designed to burn fine screenings or slack coal because this is the cheapest form in which coal can be purchased. This will require a grate designed to prevent the finer particles of coal sifting through it. Yet the grate should have large area of air openings in order for the air to find ready access to the fuel. If the air passage through the grate is restricted, a high air pressure for the forced draft will be required.

Some forced draft systems for kilns firing fine coal, require as high as 2 or 3 inches of pressure which I believe to be an indication of a poor grate design, or a fuel bed which is too thick, or both. The thicker the fuel bed, the greater will be the necessity for introducing secondary air because this is more closely reaching a gas producer condition of the fuel bed, and the proper regulation of a secondary air supply to secure economy is very difficult.

Provision for Removing Ashes from Windbox.—The stoker construction should prevent the air passages or windbox under the grate from filling with fine ashes. This can be done by providing an automatic means of removing them. This is necessary since it is practically impossible to design a grate which will not allow some siftings to work through it. However, the design of the grate, etc., should be of such a nature that these siftings will consist of fine ashes, and not fine coal.

The main ash discharge should not be into a forced draft windbox below the grate as this will require shutting off the draft to clean out these ashes, and if this process should be neglected, it might result in burning out the grate. No good stoker design would require that either the feeding of the coal or the draft be shut off in order to remove the ashes.

Stoker Should Have Ample Capacity.—The stoker should have ample fuel burning capacity without being forced, since any stoker, forced beyond its proper rating, will discharge considerable unburned fuel with the ashes. When operated at a normal rating, a proper design will insure a very small per cent of combustible in the ash.

Means for Varying Air Excess.—The stoker should be capable of producing either reducing or oxidizing conditions of the gases. It should be able to furnish the amounts of excess air at the various stages of the burn which are consistent with good burning practice.

Character of Coal Effects Design.—The stoker should be capable of properly handling the kind of coal it is expected to use. Coking coals will require some agitation during the distillation period when the coal has a tendency to stick together in large masses. Agitation will prevent the formation of such masses and keep the fuel properly open for the passage of the draft. Such agitation of the fuel at this particular time does not cause clinker formation.

Grate Should Be Close to Kiln Floor Level.—The stoker should be designed to have its grate surface reasonably close to the level of the kiln floor. This will not be difficult to accomplish if the kiln floor is above the outside ground level, but if the kiln floor and the ground are on the same level, then unless we resort to an objectionable pit to set the stoker in, the grate level will be above the floor level. In this case, forced draft will be found to overcome largely the objection of having the grate level above the kiln floor. With the stoker we have developed, we can hold this difference of level between the kiln floor and the grate to 19 inches.

Another feature in connection with the location of the grate is the desirability of having as much of the grate area as possible close to the bag wall. This will tend to keep the heat away from the arch through the kiln wall, and concentrate it more on the bag wall where it more properly belongs.

Accessibility of Fuel Bed.—Means should be provided to allow ready access to the fuel bed for purposes of inspection and to allow hand firing if found necessary.

In conclusion, I would say that I appreciate the idea that a kiln stoker has generally been given very little thought in our industry. I hope the outline I have given above of the requirements of a good stoker will not discourage you into believing that no stoker could possibly be designed which could measure up to that rather formidable list, unless it was such a complicated machine as to be too costly to install, or if installed would require a corps of experts to operate it. Such is not necessarily the case, as a properly designed kiln stoker can be a practical and reliable machine.

STRAITSVILLE IMPERVIOUS BRICK CO.
NEW STRAITSVILLE, OHIO

SUBSTITUTING FUEL OIL FOR PRODUCER GAS IN A CONTINUOUS GLASS TANK

BY F. S. THOMPSON

Although oil as fuel had been used before on the twenty-ton continuous tank of a New England glass factory it was considered expedient, during the late coal shortage, to try the oil under operating conditions over a long period of time. Our previous experiments and experiences with fuel oil, as written up and reported elsewhere, show that the time covered in each case was short and that considerable trouble developed in maintaining the temperature of the checkers and also in securing the proper difference in temperature between the melting end and the working end.

In addition to warming the tank and trying short tests with fuel oil, it was used each Saturday for a period of one to two hours while the producer gas was turned off for cleaning the mains. At this time two burners were used. They were mounted above and on either side of the dog house and played their flames horizontally into the tank. One burner was turned on while the furnace valves were arranged for the incoming air to enter on the same side as itself. When the furnace valves were reversed that burner was turned off and the other turned on. This system caused the flame always to be projected past the four ports which were supplying the necessary secondary air. It was noted that the flames passed longitudinally to the front of the furnace passing the ports *at a point horizontal from them*.

When sufficient oil was turned on to maintain the working end at the proper temperature, a long flame developed which swept down one side of the furnace for a distance of more than thirty-five feet and horse-shoed back. Obviously this caused an even distribution of heat and a consequent evening of temperature between the working and melting end. The result would be that if the melting end were hot enough properly to melt the batch, the front end would be too hot for working. Conversely, if the working end were at the desired temperature, the melting end would be low and would soon result in the production of seedy glass.

To offset this undesirable condition the engineers of the W. N. Best Company of New York, whose burners we have used for several years, were consulted. They recommended that in addition to the two burners already in use we install two additional burners, one on each side of the furnace above the bridge-wall. These burners were to project their flames at an angle of 45° and toward the rear, or in other words in opposition to the flame of the original burner in the rear of the tank. The purpose of these additional burners was not only to furnish more heat to the melting end, but to play against the burner operating from the rear and prevent it from "horse-shoeing" around the working end of the tank. The result of this arrangement seemed to produce the desired conditions.

Attention should be called to a point that at the time did not appear at all important, but which, in the light of subsequent events, proved to be of the greatest significance. That is, when the additional burners were installed at the side the burners in the rear were lowered about twelve inches. This lowering brought the rear burners into a position from which they were able to inject their fuel directly into the downward projecting secondary air. This point will be brought out later.

The test run with this arrangement of burners was of eighty-nine hours duration. During this time the producer was shut off and the gas from the hot mains and the smoldering fuel in the producer was shunted to the stack. The Westlake machines, three in number, continued to operate throughout the period. The important events of the run we might chronicle briefly as follows:

First Day.—After closing the gas valve above the Forter valve one side burner and its corresponding rear burner were turned on. Each pair of burners on the respective sides were operated with a common valve in order that they might be turned on and off simultaneously from one point. At reversals (every half hour) the Forter valve and air intake were first reversed after which the lighted burners were extinguished and the opposite side started.

Since the secondary air, under oil firing conditions, can be drawn through both air and gas regenerators the big drop doors on the Forter were each wedged up three inches to allow an inlet to the gas tunnel. This not only resulted in more efficient regeneration but insured a more even temperature between the two chambers.

Although no particular manipulative difficulties were encountered the temperature was not maintained as steadily as was customary with producer gas.

Second Day.—The burner operators, having become accustomed to their work, were now holding the working end of the furnace within plus or minus five degrees.

The checker temperature, in which we were particularly interested, maintained a very satisfactory condition; in fact the color seemed even brighter than under producer gas conditions.

Third Day.—The events of the twenty-four hours represented by this period were practically a repetition of those of the previous day.

Fourth Day.—The first ten hours passed with unchanged conditions. At 10 o'clock A.M. the individual control valve on one of the side burners was broken off. As the test run was about finished, this burner was cut out and its corresponding rear burner operated alone on that side.

This break occurred at just the opportune time to prove to us that the side burners were unnecessary *provided the rear burners were placed in the proper position*. As mentioned before the rear burners were, at this time,

lower by twelve inches than in any previous test run of oil. It seems reasonable to conclude that with the rear burners too high the fuel was projected over the incoming streams of secondary air and beyond them thus preventing an intimate mixture. However, with the fuel injected directly into the path of the incoming air the mixture was complete and intimate and caused a flame that expended itself in the melting end and brought the desired relative temperatures between the melting end and the working end of the tank.

The test run was brought to an end by turning in the producer gas after eighty-nine hours of oil fire. The working end thermo-element in the front wall showed that during the last fifty hours of the test the temperature at that point maintained practically constant. However, the machine operators reported that the glass worked from the side boots varied in temperature with the reversals. No measurement was taken to verify or disprove this assertion. In the light of subsequent events however we were led materially to discount any effect this variation had.

Viewing the matter from a comparative cost standpoint not only the cost of the fuels must be considered, but also the cost of labor and the operation of auxiliaries, such as coal elevators, oil pumps, etc.

The cost of firing the furnace with producer gas will be considered first. The following items show the expenditure for the various operations and labor and the total cost per day.

Producer power	}	.....	\$2.20
Coal crusher power			
Coal elevator power			
Coal scale			
Producermen.....			15.12
Coal man.....			4.40
Removing ashes.....			1.10
Average daily consumption of coal (13.5 tons) in producer.....			94.50
Cost of steam.....			28.80
Burning out mains (one-seventh of cost).....			2.00
Producer repairs.....			1.00
Interest on investment and depreciation.....			7.00
Total			<hr/> \$156.12

In a similar manner we arrive at the daily cost of operation with oil.

Cost of average daily consumption of fuel oil (2167 gal. at 4.5 cents).....	\$97.52
Cost of delivery to burners.....	22.00
Cost of delivering air at 60 lbs. pressure to burners.....	8.00
Repairs and upkeep on air compressor, oil pump, and pipe lines.....	3.00
Interest on investment in compressor, oil pump, and pipe lines.....	.50
Depreciation on pumps and lines.....	.50
Labor (three men 8 hours each).....	13.20
Total	<hr/> \$144.72

From a dollar and cents viewpoint, therefore, the advantage lies slightly with the oil. The question of the destructive action of the oil flame has never been a very serious one in this particular furnace. Probably the position of the burner has a bearing on this phase. Since running the test we have been discussing, this same furnace was run for nine months on oil without any noticeably bad effects.

Results and Conclusions

1. The total time of operation was eighty-nine hours and the total quantity of oil burned was 8035 gallons or an average of 2167 gallons to each 24 hours.

The oil used was brought from the Providence refinery of the Standard Oil Co. and showed a heat value of 18,980 B.t.u. per pound or 6,244,420 B.t.u. per barrel. The test was made by a bomb calorimeter in the East Providence laboratory of the Standard Oil Co. Its gravity was 19° Baumé.

In a paper by H. C. Sherman and A. H. Kopff,¹ the following formula is given for the calculation of the B.t.u. value of an oil from its Baumé gravity reading:

$$\text{B.t.u.} = 18,650 \text{ plus } 40 (\text{Baumé} - 10)$$

Substituting we have

$$\text{B.t.u.} = 18,650 \text{ plus } 40 (19 - 10)$$

$$\text{or B.t.u.} = 19,010$$

Since this figure checks within .15% of the calorimeter determination we can safely assume the result to be correct.

As before stated our test run consumed 2167 gallons or 51.357 barrels of oil per day. At 6,244,420 B.t.u. per barrel the thermal value of one day's fuel would be 320,694,677 B.t.u.

The B.t.u. of the coal from our storage averages 14,000 units. Dividing the number of units fired per day in oil by the number of B.t.u. per pound of coal, gives 22,906 lbs. or 11.453 tons of coal as the equivalent of the oil consumed.

Since the average daily consumption of coal on this furnace was 13.5 tons (short) or 27,000 pounds, the comparison on a strictly thermal basis is also in favor of the oil.

2. The checker work of the regenerators maintained a very satisfactory condition, although a slight deposit of carbon formed on the top layers. This carbon, we think, might have been the result of insufficient air at times during the experimenting with drafts and intakes. At such times when we throttled the intake too far the combustion was naturally incomplete and resulted in the deposit on the bricks.

¹ *Jour. Amer. Chem. Soc.*, October, 1908.

3. The flue gas which was analyzed daily indicated that after the first twenty-four hours our stack and damper regulation was very nearly as efficient as could be obtained. On April 28th the flue gas showed 14% CO₂. The next day it was twice analyzed at 16% and remained at that figure throughout the test.

4. Each of the four oil burners were protected during their respective periods of idleness by a fire-clay tile one foot square and an inch and one-quarter thick. The two tiles on each pair of burners were each suspended by a cable running up over a pulley and down to a common counter weight near the oil control. Thus, when turning on or off one pair of burners their doors could be raised or lowered, as desired, simultaneously and from a point near the oil control. This proved a very valuable aid in the operation, although the design of the pulleys should be changed to prevent the cable from slipping off.

5. The fuel oil (18° to 20° Bé) supplied by the Standard Oil Company was found to be more easily manipulated than the heavier oil used on the previous tests. The principal difficulty encountered in using the heavy oil in addition to that of maintaining a hot supply lies in the trouble encountered in starting a burner that has been idle during reversing periods or for any other cause. A few moments lost periodically in this manner causes losses that are far greater than the difference in cost between the two oils. Even circulating pipes and elaborate heaters do not seem to be the answer to the intermittent oil burner.

6. It is not unreasonable to state that if the problem of burning fuel oil instead of producer gas in the tank furnace be properly attacked and followed through, that the oil would prove fully as efficient and as satisfactory.

7. The main object of the test was to determine the practicability of fuel oil as a substitute in case of emergency, such as might be caused by a long continued coal strike. From this point of view the experiment was entirely successful.

Appendix

Since the foregoing test was finished and recorded the furnace in question has operated almost continuously on fuel oil of 18 to 20° Baumé gravity.

The fuel is supplied to the furnace through the rear burners only, one at a time. The daily consumption of oil is now about 1935 gallons. It will be noted that this consumption is somewhat lower than that attained during the test run. This lowering of the consumption of oil might be accounted for in slight changes in furnace design (elimination of hollow tongue tile), new furnace bath with its thicker walls, or to more thorough experience in operation.

In September this particular furnace was let out for three weeks for repair. During that period a shift was made in the position of the burners but after several experiments (in warming up and afterward) the burners were returned to the position that gave the best results as before described.

When the furnace was first built in 1920, eight burner holes were made on each side of the furnace. These were situated one on each side of each of four ports. This design intended to play two streams of vaporized oil into each current of incoming preheated air. This scheme, while apparently correct in theory, was never put to use on account of the unwieldly number of burners to be handled.

This short paper has not been written with any idea of setting forth anything startlingly new in oil burning but on account of the fact that this particular furnace is used for the manufacture of glass which demands accurate temperatures within very narrow limits. We merely wish to establish the fact that such a temperature condition can be maintained with oil as fuel without detriment to production.

Discussion¹

S. R. SCHOLES:²—While the writer's experience with fuel oil here is limited to a brief run, it happens we used the same type of rear burners as those described by Mr. Thompson. Our results so far as maintenance of temperatures is concerned were good, but since we paid more for oil and less for coal than the figures cited, economy was on the side of coal.

It appears that under the conditions prevailing at Mr. Thompson's plant, coal at \$6.16 per ton would compare on an equal cost basis with oil at 4.5 cents per gallon. No direct mention is made of the cost of steam for heating the oil, but probably this is included in "cost of delivery to burners." In cold weather this runs relatively high.

One item of cost of operating gas producer, "cost of steam, \$28.80," seems too high. (Probably not more than 60% by weight of the coal gasified, or 8.1 tons of steam was blown in per day.) Assuming a low boiler efficiency and taking 4 pounds water evaporated per pounds of coal fired under the boiler, 2.05 tons of coal would be used for this purpose. This would cost \$14.35; and the firing labor must certainly be incidental to other duties, and come well under the remainder, $\$28.80 - \$14.35 = \$14.45$.

¹ Received Sept. 8, 1923.

² Federal Glass Company, Columbus, Ohio.

FUEL OIL AS ADAPTED TO THE CHAMBERED CONTINUOUS KILN

BY MARK A. TAYLOR

ABSTRACT

A summary of equipment used and methods employed in firing a Youngren type kiln with fuel oil. Includes a description of storage tanks, pumps, heater, oil distributing system, meters and strainers, atomizing medium, burner headers, and burners. The kiln successfully burns a uniform, high quality ware, and has been in use eleven years, with oil as the only fuel.

Introduction

Fuel oil is rapidly growing in importance in ceramic manufacturing. Pertinent data on this comparatively new fuel is being continually gathered and presented. The clay worker who is interested will first make a study of oil itself and then of oil-burning installations in which conditions parallel or correspond to those at his own plant. It will eventually be necessary to have reports covering every important type of kiln in use, for each type requires a typically different lay-out for oil burning. A few kiln types have already been interestingly presented. This paper covers only the continuous chamber kiln.

The Kiln

The Youngren type (Goldner Patent) kiln of the Vincent Clay Products Company of Fort Dodge, Iowa, was built in 1911, and from that time to the present has used no other fuel than oil. The product has been largely drain tile, and occasionally building block.

Storage Tanks

Fuel oil is stored in three similar steel tanks of combined capacity of 60,000 gallons. These tanks are sunk in a concrete pit so constructed that there is working room at the sides and ends of the tanks. The pit is well drained. It has a reinforced concrete cover that will withstand heavy loads. The three tanks lie end to end along a railroad siding, and are sunk deep enough to allow the oil to flow by gravity from tank cars. The 1½-inch suction line extends over the top, and drops into each tank to within 9 inches of the bottom. This clearance prevents water and settlings from entering the line. A screened foot valve is fitted onto the suction line in each tank. The return line empties near the foot valves, so that the hot return oil warms up the surrounding oil.

Pumps

Located in a small building at the end of the tank nearest the kiln are two Fairbanks-Morse oil pumps. One is a two cylinder piston pump,

the other a double plunger pump, but both are designed to handle hot oil. Only one pump is in use at any time, the other being held as a reserve in case of a breakdown.

A one horse power Fairbanks-Morse motor drives either pump. Approximately five times as much oil as is used on the kiln is delivered through the line.

The pumps are placed a little below the level of the tops of the storage tanks, so that the suction lift is reduced to approximately seven feet.

Both the main oil line and the return line are led from the pumphouse through a tunnel to the main building. Thus the underground joints of the lines are always accessible. This tunnel was built after twice digging the lines out of frozen ground to repair leaks.

CROSS AND LONGITUDINAL SECTIONS
SHOWING BURNER PLACEMENT

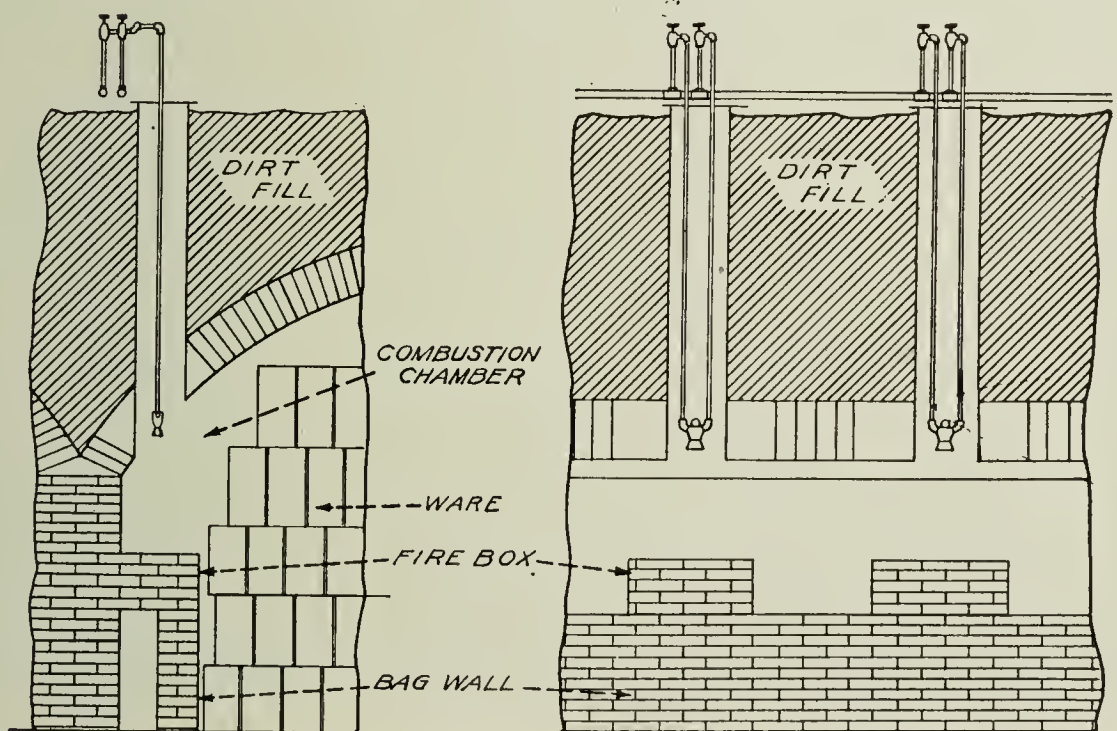


FIG. 1.—Two burners connected and in firing position.

The Heater

From the entrance to the building the lines go to the main waste heat flue at a point 60 feet from the kiln. The oil may be delivered direct to the kiln by a line outside the flue, or it may be diverted into a home-made heater placed within the flue. Both delivery and return lines have this heater feature. The heater in each case consists of three fifty-foot lengths of 3-inch pipe. By the time oil passes through this 150 feet of piping surrounded by an atmosphere at a temperature of from 400° to 500°F, the oil temperature is raised to between 150° and 200°F.

It is possible to use either or both of these heaters or to cut them out of the line altogether. Each heater may be well drained when not in use.

It would seem that any predetermined temperature of the oil could be maintained by dividing the flow as it gets too hot, and sending only a

fraction of the total supply through the heater. But by doing this, so small an amount of oil would pass through the heater that overheating would result, causing some of the oil to gasify, and slowly carbonize in the heater pipes. This would make trouble at the burners, eventually clogging them.

This heater will seem crude to those familiar with precise steam heaters automatically controlled. But at this plant, steam is not available continuously. The only available boiler is a small oil fired affair which is fired occasionally to heat up a tank car, or to warm up thick oil in the storage tanks following a shut down. The steam line from this boiler is led with the two oil pipes through the tunnel and pumphouse, and over the tanks where it is connected to a heating coil in each tank, and also fitted with a connection for tank cars.

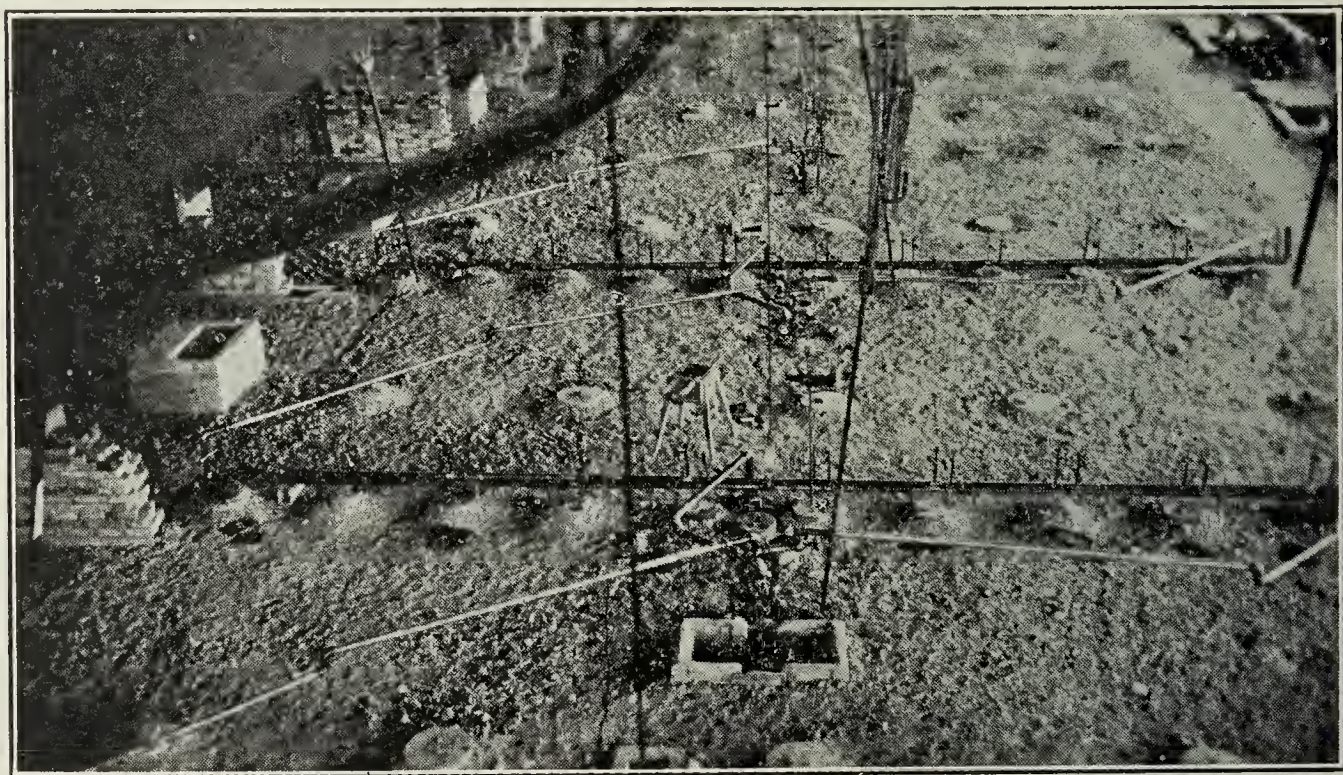


FIG. 2.

Note: Main oil and air lines are buried about one foot under the loose crown insulation. Brick well foreground houses a union coupling on main oil line. Portable Brown pyrometer used on oxidizing chamber, and draft gage are shown in the center of the view. Rectangular brick box at center-left contains sliding waste heat damper.

Oil Distributing System

The pipe from the waste heat flue to the top of the kiln is reduced to $1\frac{1}{2}$ inches. When first installed the oil was piped clear around the kiln in a single line which entered on one side of the kiln, passed down the kiln over the center of each chamber, then crossed over at the rear of the kiln and returned on the other side in the same relative position. Risers were provided for each chamber, and oil was distributed to separate chambers by means of movable headers, three of which were used. Oil entered these headers at the center and flowed as fast as used by the burners.

towards the two dead ends. Excess oil never entered the headers, but passed on through the main line to the return. Each header was equipped with a small fish trap screen and oil meter.

This type of header was a source of much trouble, especially in cold weather. At the start of a burn, with only a few burners in use, the oil would flow so slowly through the header that it would cool and thicken before it reached the burners. No matter how careful a fireman might be, it seemed as though the fires were either much too strong, or else not burning at all. Much ware was lost from this cause, as the early stages of the burn requires the most careful operation.

A new distributing system has been evolved which obviates all dead ends, and while more complex than the old, the new lay-out is easily understood and already has proved to be a very good investment. The oil line around the kiln was left as before, except that stopcocks were placed in the line ahead of each riser. Each header was fitted with long swinging pipes at each end. One of these pipes was connected to the riser in front of the header and one was connected to the riser behind.

It can be seen that if both riser valves are opened, and the stopcock in the main line between the risers is closed, all of the oil must of necessity flow around through the burner header. As there are three of these movable headers set up on successive chambers, it was necessary to arrange the fittings on the risers so that the oil could be passed either directly into the header ahead, or down into the main line. Figure 2 will show how these fittings are assembled.

Meters and Strainers

It was impossible to use meters and strainers as in the old system, for the meter would register the oil that passed back to the storage tanks as well as that which was burned. Two sets of large strainers and meters were therefore connected into the line, one set where the line enters the kiln and the other on the return line where the excess oil leaves the kiln. Thus the difference between the two meter readings over a given period will give the oil burned in that time.

The 1 $\frac{1}{2}$ -inch meters are manufactured by the Pittsburgh Meter Company and are designed especially for fuel oil at 150°F. The strainers are the two way or duplex type which means merely two strainers connected in parallel so that one may be cut out of the line and cleaned while the other is in use. This arrangement precludes the necessity of shutting down the fires to clean a dirty screen.

A duplex screen is set up with each meter so that the oil is strained before entering the meter.

The separate strainers are of the 1 $\frac{1}{2}$ -inch fish trap type, manufactured by the Pittsburgh Meter Co. The screening element was originally a

fine wire gauze backed up and strengthened by a coarse meshed screen. Experience showed that the wire gauze offered so much resistance to the pump that proper oil pressure could not be maintained at the burners. Therefore the fine screen was eliminated leaving only the coarser mesh.

The only trouble resulting from elimination of the fine screen was the necessity of occasionally cleaning the meters. In any case the screen mesh should be smaller than the oil delivery nozzle in the burner.

An oil pressure of 30 pounds per square inch is maintained on the line by means of a weighted bypass valve on the return. White lead on all thread joints is sufficient precaution against leaks at this pressure.

Atomizing Medium

Compressed air is the atomizing medium used. This is furnished by a 14 x 10 Ingersoll-Rand compressor, driven by a 25 h. p. Fairbanks-Morse motor.

Air pressure is maintained at 20 pounds by means of an Ingersoll-Rand unloader. This device has paid for itself many times over, as through its use the compressor runs idle more than half of the time. In principle, this unloader consists of a valve in the air intake line which is actuated by the pressure in the storage tank. At 21 pounds pressure, the valve closes instantly, and the compressor runs idle until the pressure drops to 19 pounds. Then the valve opens, the compressor pumps the pressure up to 21 pounds, and the cycle is repeated.

Air is carried from the compressor to a tank 8 feet long and 4 feet in diameter, which serves to minimize the pulsations of the compressor. A 4-inch main leads from this tank to the top of the kiln and there is divided into 2 two-inch lines. These lines pass close to the oil lines down each side of the kiln. Risers are provided for each chamber, close to the oil line risers.

Burner Headers

The three movable headers are made up of the 1½-inch oil pipe described previously, and a 2-inch air pipe. When in use, the air pipe is connected in its center to the main air line riser, and the oil pipe is connected as previously described.

There are eleven fire holes to a chamber. Risers, ¾-inch, are fitted onto both air and oil pipes opposite each fire hole. Each header is 30 feet long and the burner connections are 3 feet apart.

The two main pipes are clamped firmly together and the headers are easily moved to any chamber of the kiln by means of a half ton chain hoist and overhead trolley.

Two chambers are on fire at once, one oxidizing, and one full fire, so that there is plenty of time to move the third header forward and make it ready to light.

Burners

Number I Schurs burners are used. These must be fitted up according to the special requirements to be met. Each burner is fitted with $4\frac{1}{2}$ feet of $\frac{3}{8}$ -inch pipe on both air and oil intakes. This length of pipe allows the burner to project down until the tip clears the inside of the crown arch. Both of these pipes are equipped with ground union fittings at the top, so that they may be quickly fitted to or detached from the header.

Eighteen burners is the maximum in use at one time. Eleven on the full fire chamber, and seven on the oxidizing chamber.

The sketch shows a burner in place, with relative positions of crown, bagwall, and ware. Number one ware is obtained next to the bag wall in spite of the short hot flame necessitated by this construction. A strong draft must be maintained to distribute the heat, or over-burned ware along the bag wall will result.

Conclusions

This kiln gives uniform burns of a fine quality ware, and with but a fraction of the labor necessary on coal fired kilns.

Complete data on oil and power consumption is available, but is considered misleading and useless as general information for two reasons. (1)—This particular plant has never used any fuel but oil, so that a comparative analysis of fuel values is impossible. (2)—Each separate installation has so many different and distinct factors which affect fuel consumption that data on this certain case would not apply to any other, and might serve to mislead, rather than to assist.

However, the writer is enough of a believer in fuel oil to state that this concern has been successfully meeting active competition of coal fired plants for more than eleven years. And in the end, survival is the acid test of any system.

FORT DODGE, IOWA

COLD END COMPENSATION ON A PYROMETER SYSTEM¹

BY CHARLES B. THWING

ABSTRACT

Attention is called to the fact that every measurement involves two quantities and that failure to correctly determine either leads to erroneous results.

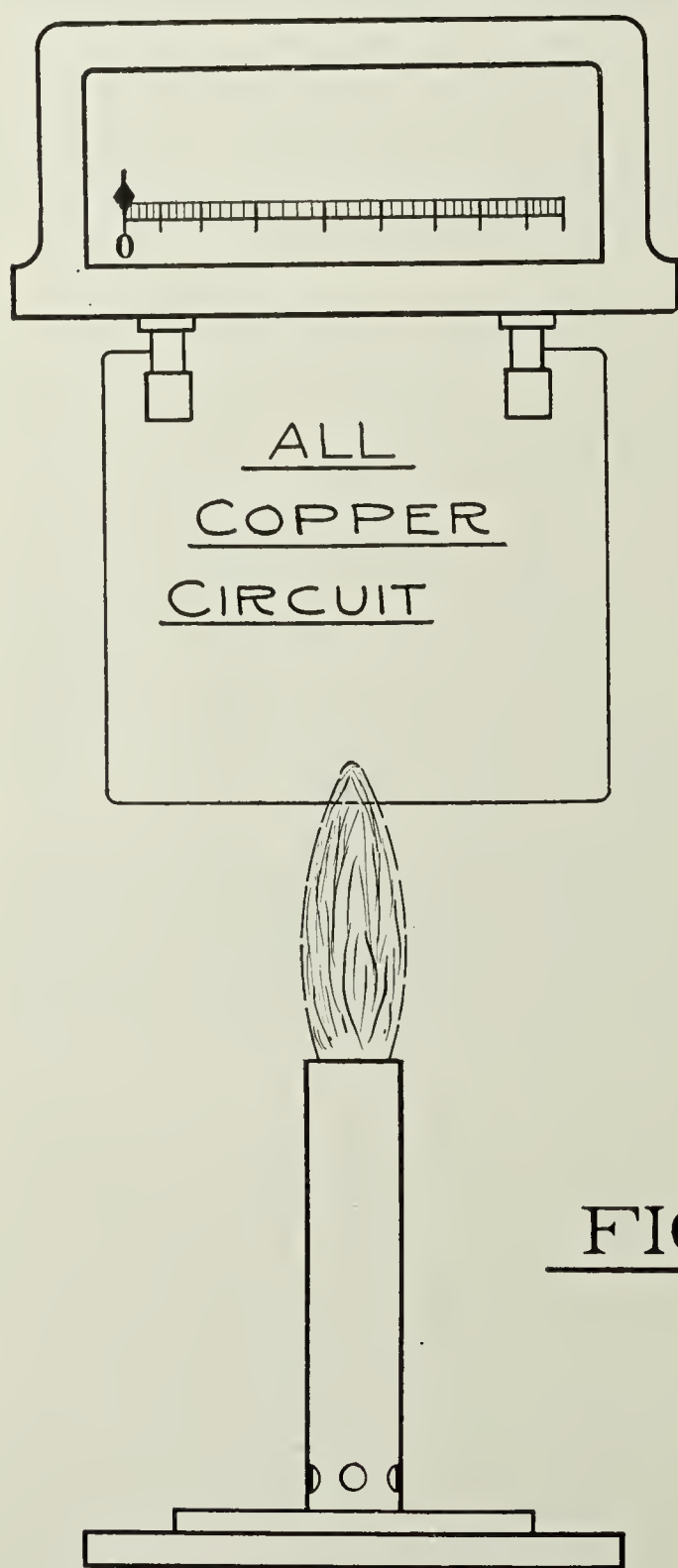
The large cold end variation present in the usual method of mounting thermocouples in brick kilns is pointed out and an improved method shown.

Various plans for converting the cold end error are described.

The measurement of temperature is by no means a simple operation because it cannot be measured directly by comparison with a unit of the

same quantity repeated a suitable number of times as length or weight is measured. Measurement can only be made indirectly by its effect on a quantity that can be directly or indirectly measured.

Kiln temperatures are now measured by the thermoelectric pyrometer, a device in which temperature changes produce an electric current which, in turn, produces the mechanical movement of a needle across a scale. The first operation in making a measurement of length with a micrometer, for example, is to test the zero of the micrometer, that is, to measure zero length to see if the point of reference agrees with the zero mark on the scale. Again, in surveying, it is just as important that the chainman who follows, place his end of the chain at the center of the pin as that the forward man set the next pin exactly at the end of the chain.



No chemist would make a weighing with a sensitive balance without first testing the zero of his balance. These are common places to men

¹ Presented before Heavy Clay Products Division, Pittsburgh Meeting, Feb., 1923.

accustomed to making the measurements referred to but persons unaccustomed to the use of pyrometers are prone to forget that a thermocouple has two ends, one of which is the point of reference. To ignore the fact that the point of reference may be, and commonly is, in error, sometimes by a seriously large amount, is to fail to get the full benefit of the pyrometers. For this reason the discussion of the cold end error and the various methods which may be used to avoid or to correct it is of great importance.

The nature of thermocouples is shown in the figures which follow. In Fig. 1 is shown a closed circuit composed wholly of copper wire with heat applied to a point in the circuit. Whatever thermo-electromotive force is generated between the hot junction and the meter in one branch of the copper wire is exactly balanced by an equal electromotive force in the other branch and no deflection of the meter results.

In Fig. 2 a section of nickel wire has been inserted in the circuit and heat from a bunsen burner applied to one copper-nickel junction while less heat from a candle is applied to the other junction with the result that the needle is deflected.

If while the bunsen burner continues to supply a constant quantity of heat to junction H we remove the candle from junction C, the deflection will be increased. If we cool junction C with ice a further increase in the deflection will result.

In Fig. 3 we have replaced a portion of the copper wire forming junction H with a more refractory iron wire which in turn is joined to the copper wire near C to form the typical thermocouple joined by copper leads to a meter, in other words a pyrometer uncompensated for the cold end error.

The candle remains in place as a reminder that heat is always being supplied to the cold junctions, varying in amount as the flame is blown

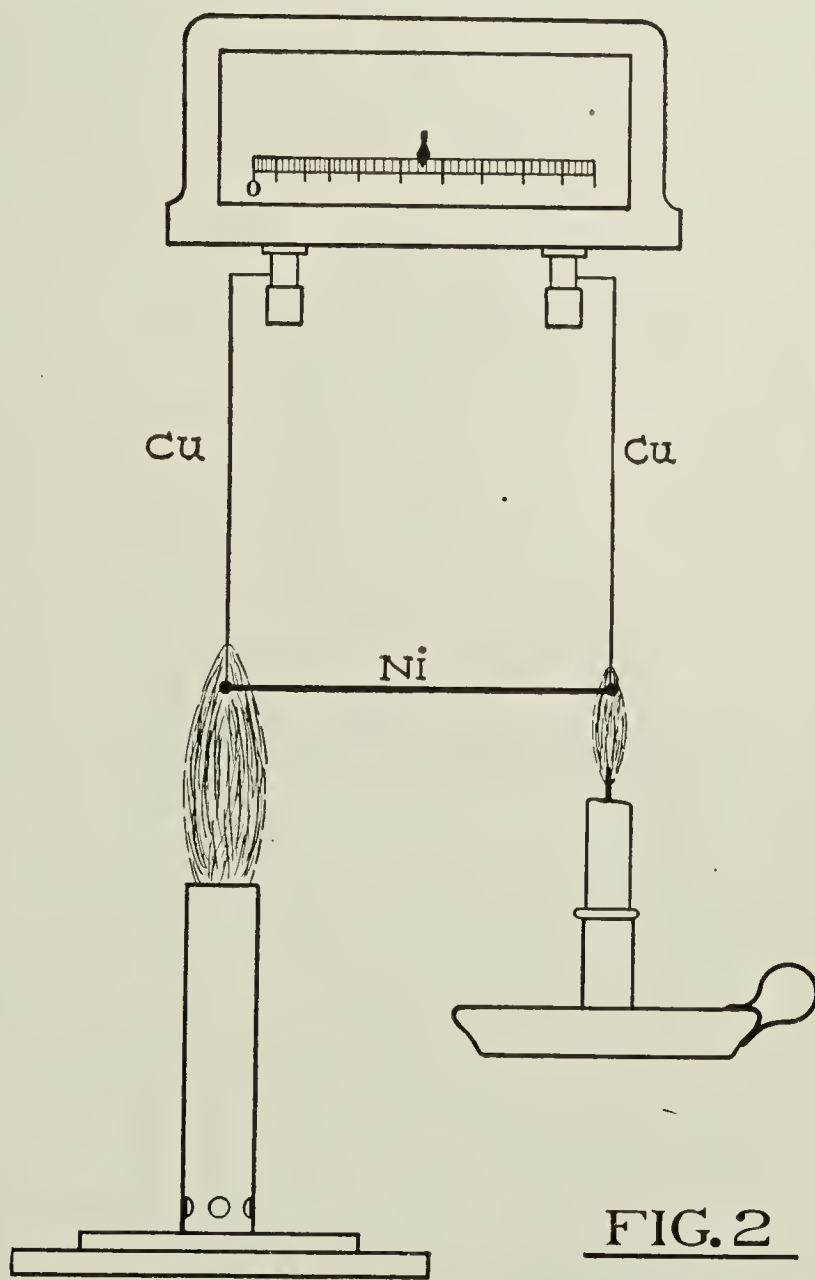


FIG. 2

by currents of air or as the candle burns down. It should be remembered that the meter is affected not only by the temperature of the hot junction but by that of the cold junction as well.

The problem is to provide means of eliminating from the meter readings the effect of changes in temperature at the cold junctions.

In Fig. 4 is shown a common method of mounting a thermocouple in a brick kiln. The cold ends are protected from the weather by a metal head which readily absorbs heat from the kiln and from the sun in daytime quickly radiating it away to the sky at night and in cold windy weather.

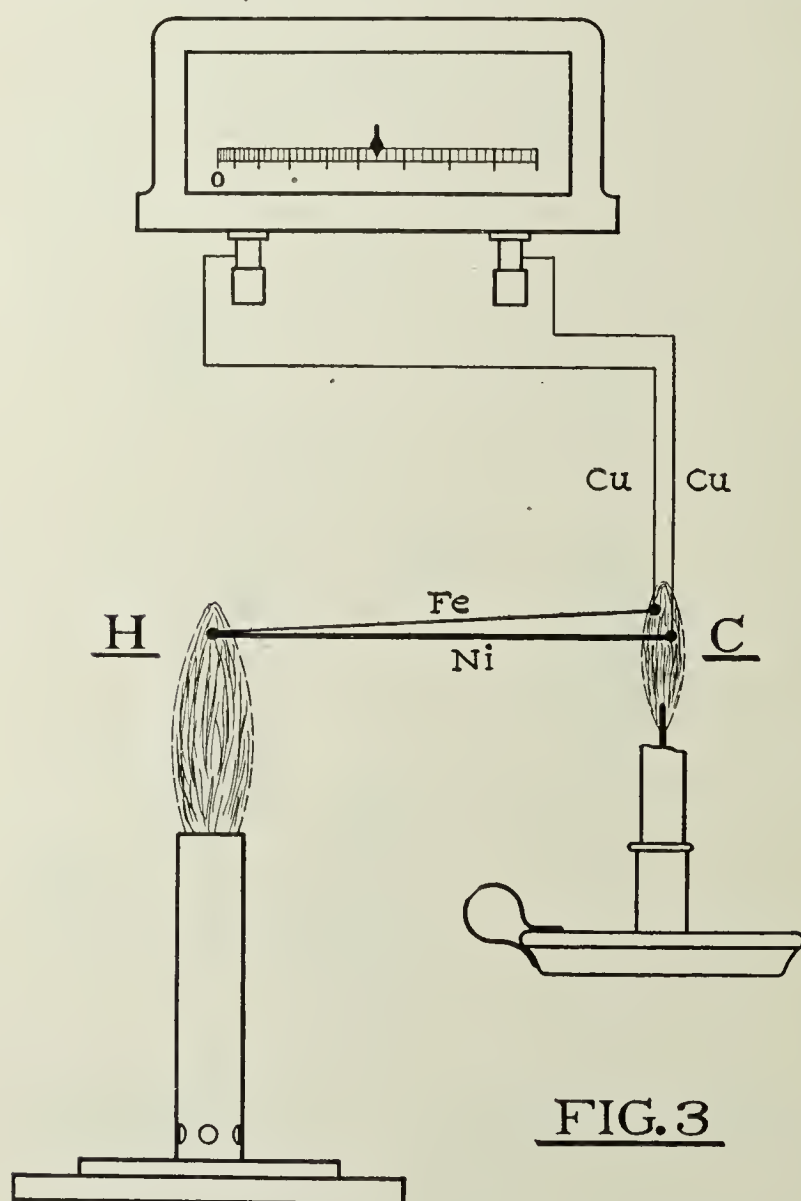


FIG. 3

The cold end variations are excessively large.

In Fig. 5 the small metal cap is replaced by a large brick box permitting the cold junctions to be set farther above the kiln crown where they are less affected by the heat from the crown. A heavy tile cover not only keeps out rain but screens the junctions from the sun and prevents loss of heat by radiation at night.

Ventilating openings on all sides allow a circulation of air. In summer all are left open, in fall and spring those on the north and west may be closed, while in the coldest weather all openings are closed.

This plan reduces the daily and seasonal variations in the

cold end temperature by fully one-half and is therefore a distinct step in the right direction gained at a nominal cost.

The error still remaining is, however, too large to be neglected. Some of the methods which have proved practical solutions of the problem will now be described. Several other schemes, some of which are theoretically correct but not workable under the conditions found in a brick plant, will be passed over so that attention may be focused on the few that are workable.

All of the plans to be described involve chasing the enemy away from the top of the kiln to a position where it can be more easily vanquished.

This is done by extending the thermocouple to a new position by the use of compensating leads which may be of the same material as the thermocouple or of other materials which, *for the lower ranges of temperature* match the couple itself. In most cases one of these compensating leads is of copper. This practically cuts the resistance of the leads in two since the resistance of all thermo-electric alloys is very high compared with copper. It also reduces the cost. In the case of platinum couples this reduction in cost is the important factor.

The first method to be described was invented and patented by the writer in 1907 when portable pyrometers were almost the only ones in use. The device was based on the principle that if the zero of the needle is set to read the temperature of the cold end there will be no cold end error. This condition was met by making the connection of the control springs of the galvanometer, not directly to the shaft carrying the coil and pointer, but through the intermediary of a spiral of thermostatic metal which automatically sets the zero of the instrument to read room temperature. (See Fig. 6.) As stationary indicators and recorders come into general use these were centrally located at distances too great to carry the cold ends because of the high resistance introduced and the plan was abandoned, to be revived in recent years since high resistance galvanometers have become common. It is now considered valuable enough to be a source of litigation.

Fortunately for the art of pyrometry other good plans are open each of which has its advantages. The choice of the one to be used may vary with the conditions prevailing at the plant.

By the plan described above the couples are extended to the meter and no attempt is made to control the cold end temperature. By the other plans to be described the cold ends are brought to one or more points which

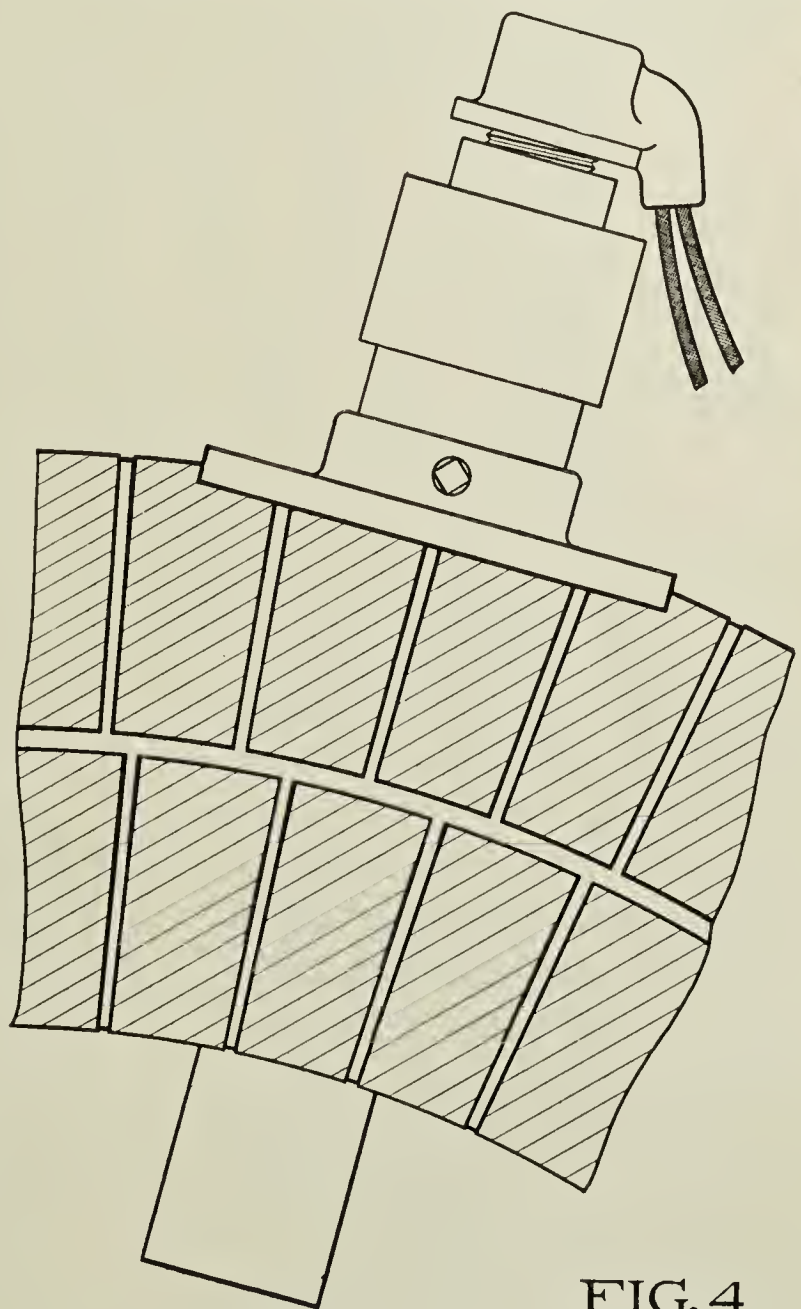


FIG. 4

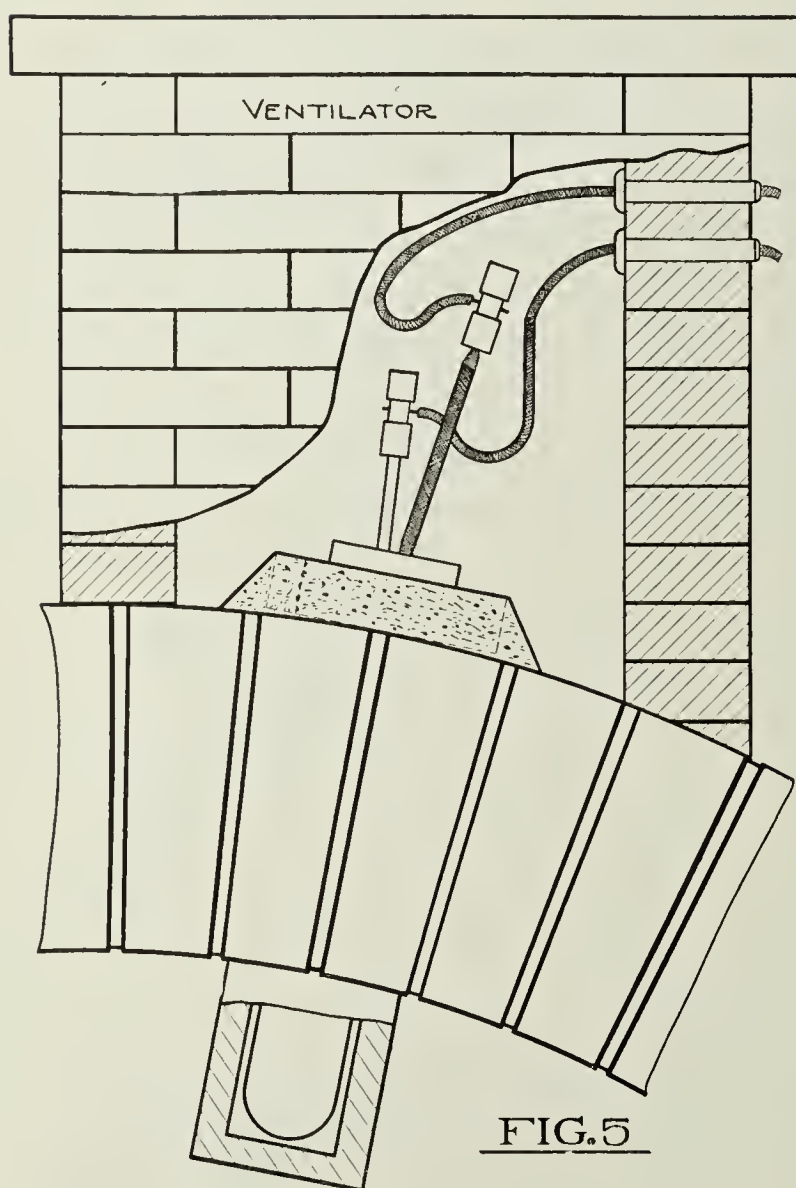


FIG. 5

illustrated in *Bulletin*, Bureau of Standards, No. 170 on "Pyrometer Practice."

It is, of course, necessary to sink the well at a point at least 20 feet distant from any ducts or pipes carrying hot gases or steam.

In situations where the conditions are not favorable for the cold well plan a third device, that may with proper precautions be made to serve, is the steam jacket. By this plan the junctions are carried in a pipe surrounded by a closed jacket to which steam of low pressure is admitted through a narrow opening at the top and allowed to escape

are maintained at a temperature practically constant and the zero of the meter is set at that temperature.

Accustomed as we are to the large and frequent changes of atmospheric temperature which prevail in the temperate zone it comes to us as a distinct surprise when we are first told that a dozen feet below the surface of the ground these changes fade out and the temperature does not vary more than 10°F during the year. All we need do therefore is to sink a closed pipe 10 or 12 feet below the surface of the ground and carry the cold junctions to the bottom of this pipe. Such a cold end well is shown in Fig. 7. Other wiring schemes are il-

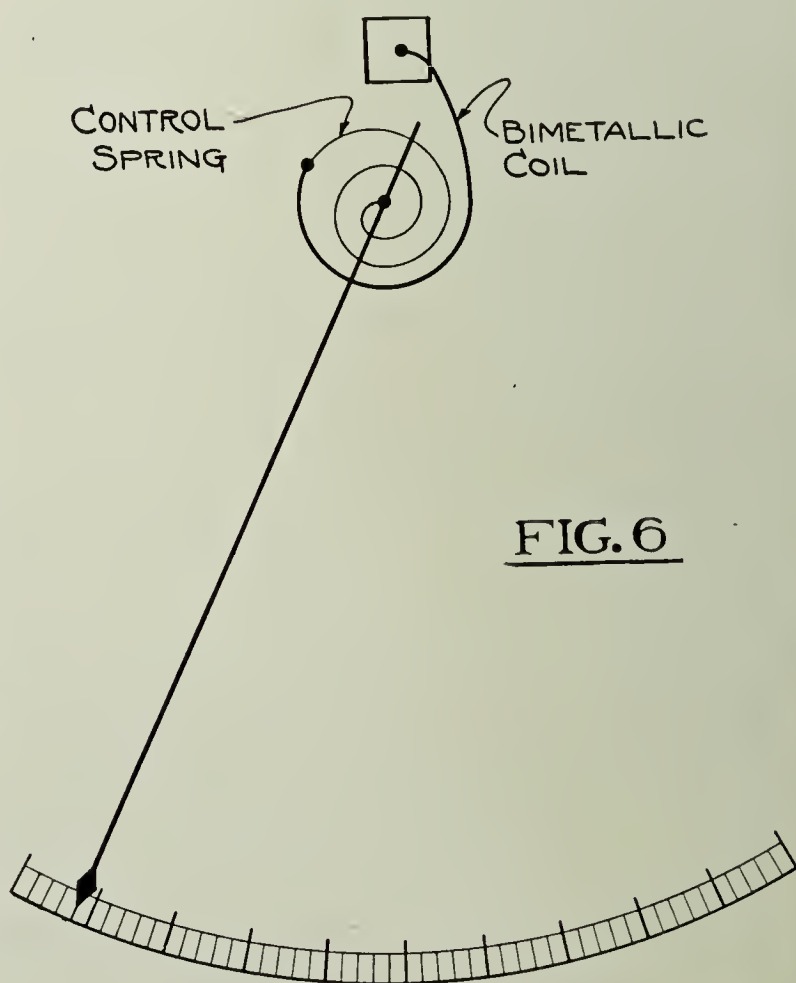


FIG. 6

to the open air at the opposite end below, thus maintaining the junctions approximately at 212°F (100°C) for which temperature the meter is set. For the successful operation of this plan care must be exercised to keep the box constantly supplied with steam, a condition which is not always easy to maintain in cold weather.

A fourth plan, which may be employed at any plant having electric current continuously available, is the thermostatically controlled junction box shown in Fig. 8. The compensating leads are joined to the copper leads at a point near the center of the box. The box contains a heating unit which is automatically cut out of circuit by a thermostat as soon as the temperature of the box reaches 120° and connected when the temperature falls below 120° . The box has a heavy cork insulation so that very little current is required to maintain the temperature.

The 120° temperature is so near the average temperature of the cold ends that any brief cutting off of the line current would produce but a small error as compared with that produced by a failure of the steam supply when steam is used.

The box may be located in any convenient place which will give minimum length of extension leads.

If the pyrometer system is not compensated for cold end error it would be well to make an experimental determination of the magnitude of the error during at least one burn. This can be easily done in either of two ways. The first is to connect

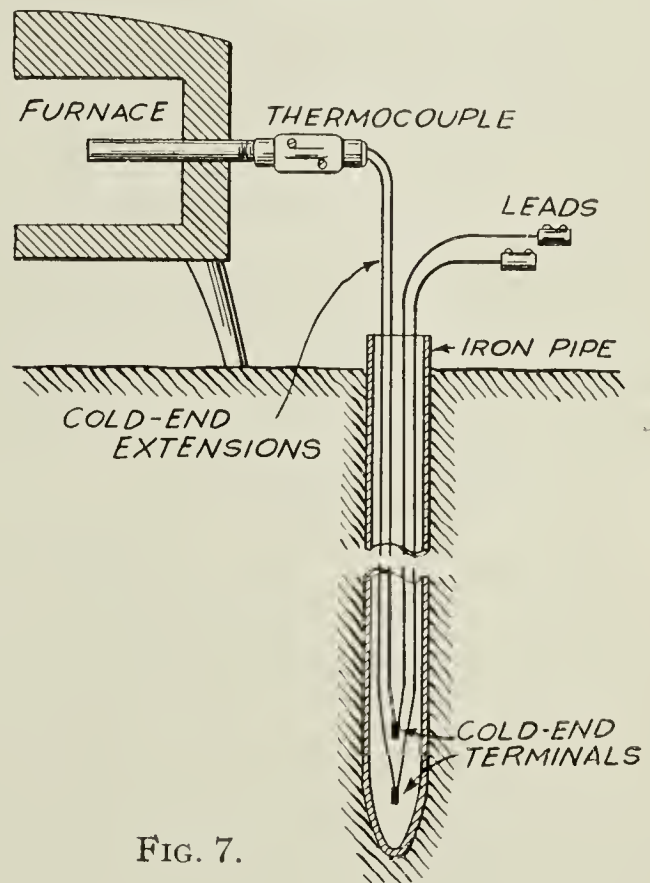
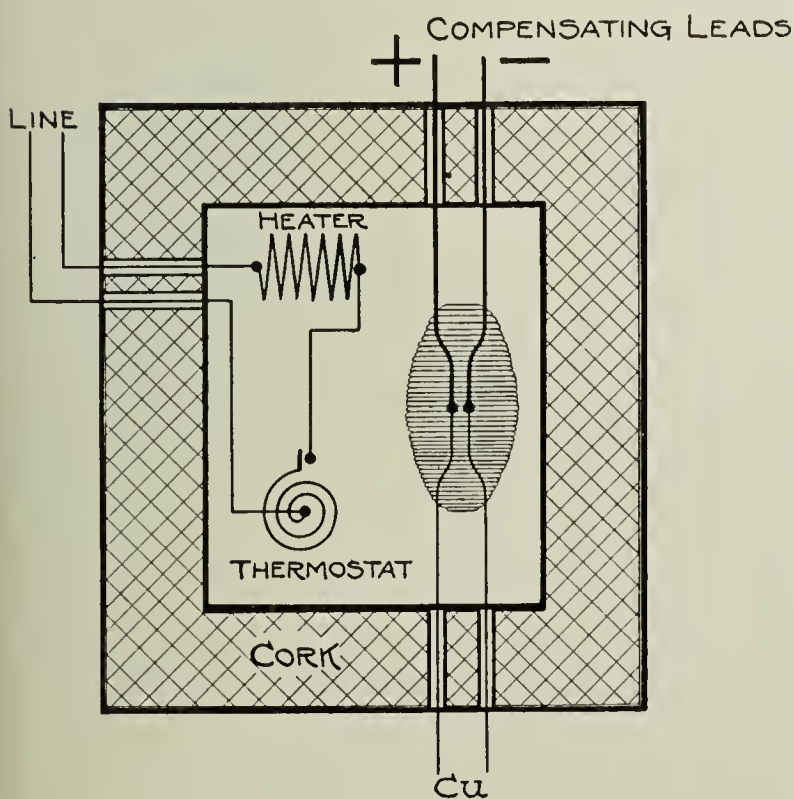


FIG. 7.

FIG. 8

connect to the terminal of a couple in parallel with the copper leads a pair of compensating leads long enough to reach the bottom of a cold end well, and

connect them to one of the recorders or to one connection of a multiple recorder so that simultaneous records are obtained from the compensated and uncompensated couple.

The second way is to place alongside the cold junctions of the couple the bulb of a low range recording thermometer and record the temperature throughout the burn. When the experiment is completed, the recorder can be hung in your office with the bulb outside the building to check the stories of the various local weather observers.

If the pyrometer system is compensated it will be of interest to know whether the results of its use justify the added cost, and also whether the recorded finishing temperatures check more nearly with the cones than is customary with uncompensated systems.

THWING INSTRUMENT COMPANY
PHILADELPHIA, PA.

INSULATION OF PERIODIC KILNS¹

By J. H. KRUSON

The cost of the burning of the ware is one of the important items of expense in all classes of ceramic manufacture and the fullest utilization of the heat developed has been the consideration prompting the development of the continuous kiln. Continuous kilns have been designed by engineers to conserve for useful purposes the calories developed in the furnaces.

The majority of periodic kilns have been built without the services of an engineer or an understanding of the flow of heat through the masonry. There have been relatively few changes in the design of the periodic type of kiln for many years and the advisability of eliminating heat losses through the use of insulating materials has been given very little consideration.

Advantages of Insulation

Proper kiln insulation not only results in greatly reduced burning costs but brings about other advantages. A much more uniform distribution of heat is made possible, which eliminates the necessity of forcing the fires and overheating the hotter portions of the kiln in bringing the cooler parts up to the desired temperature. The outer walls are protected against rapid temperature changes, reducing the danger of cracks developing with resultant air infiltration.

As is generally known, heat may be transmitted in three ways; namely, by conduction, radiation and convection. Of these, conduction plays the most important part in connection with kiln design and the amount of heat which will be conducted can be reduced or practically eliminated by installing as a component of the wall, a layer of material having a relatively low conductivity and high thermal resistance.

At least 25% of the heat generated in burning a kiln is lost by conduction through and radiation from the brickwork, and a considerable amount

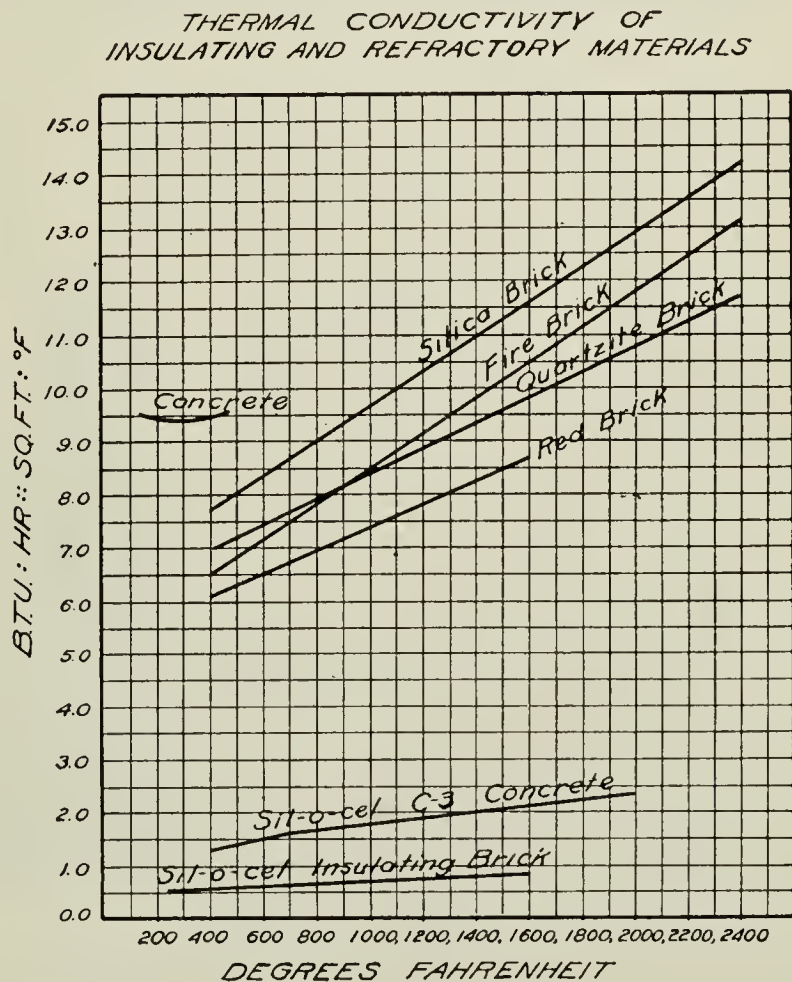


FIG. 1.

¹ Presented before the Refractories Division, Pittsburgh Meeting, Feb., 1923.

used in heating the large volume of brick in the side walls, crown, flues and the earth on which the kiln is built. On the average yard the heat loss sustained in this way is more than 25% of the fuel used.

Methods Used to Reduce Losses

Many attempts have been made to reduce radiation losses. One com-

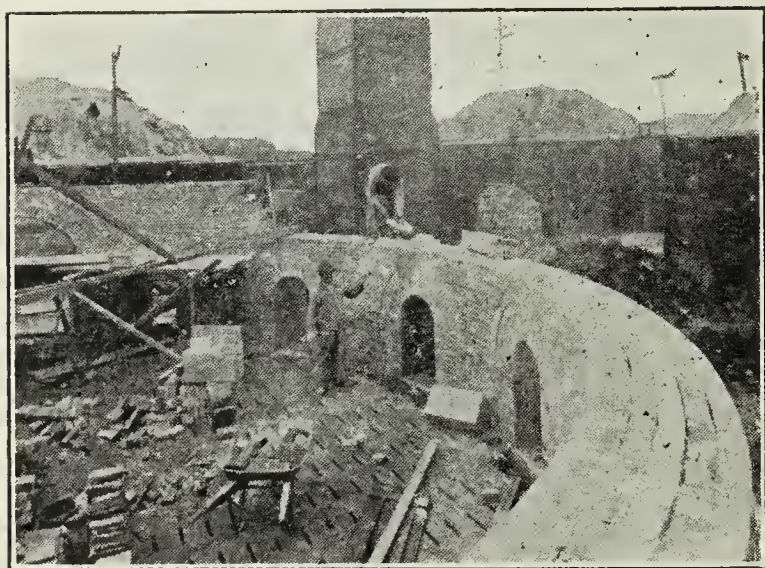


FIG. 2.

mon method was the "dead air space" between the furnace lining and the outside wall. Air is a very poor insulator, however, and after the furnace lining attains a high heat, the air will conduct the heat to the outer wall faster than even the densest refractory material. This method is effective in low temperature work but at the temperatures employed in burning brick, air currents are es-

tablished which entirely nullify any possible advantage of this construction as a means of retarding heat flow. The fallacy of the theory that air is an insulation is very conclusively disproved by Ray and Kreisinger.¹

Hollow tile and double crowns with an air space between have also been used but these methods have never been considered effective, as here, too, the air space is highly conductive.

While the use of walls four to six feet in thickness reduces loss of heat from radiation during the burn, the great mass of brickwork must be heated. It assimilates nearly as much heat as would be lost by con-

duction through a thinner wall. Furthermore, the thick walls are expensive (in material and labor) and occupy needed space.

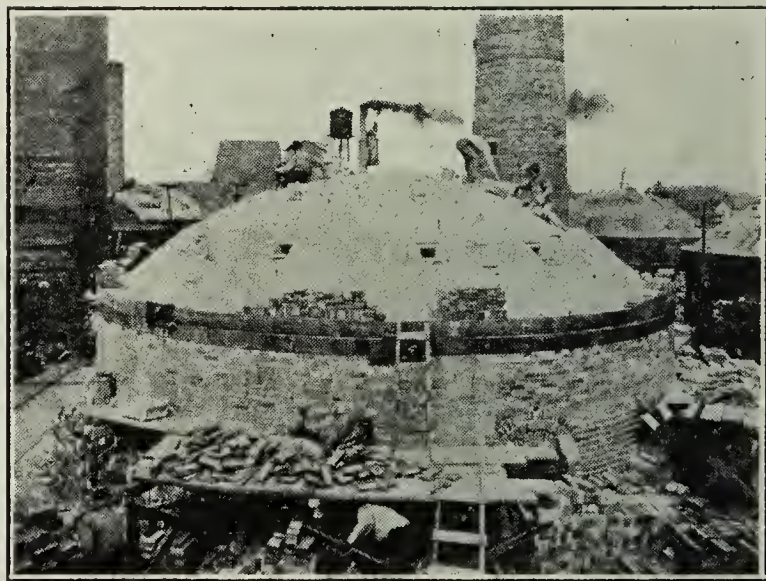


FIG. 3.

Method of Insulating Kilns

Figures 2 and 3 show a kiln under construction in which insulating brick are being used. The wall of this kiln is 27 inches thick; composed of a

¹ "The Flow of Heat through Furnace Walls," Bur. of Mines, *Bull.* 8 (1912).

13 $\frac{1}{2}$ -inch fire-brick lining, 4 $\frac{1}{2}$ inches of Sil-O-Cel insulating brick and 9 inches of fire brick on the outside. Common brick would, of course, be satisfactory for the outer wall.

The wall was bonded with metal wall ties, 12 inches long, extending across the insulation and approximately 4 inches into the other brick on both sides. In other instances where insulating brick have been used the walls have been bonded with fire-brick headers. The crown of this kiln was covered with insulating brick laid flat, 2 $\frac{1}{2}$ inches thick. These in turn were platted with a 1 $\frac{1}{4}$ -inch split fire brick. A special mortar is used with these insulating brick composed of the same material and prevents heat leakage through joints.

This particular kiln is used for the burning of refractories. In the case of kilns which are burned at temperatures of less than 2100° or 2200°F, a 22 $\frac{1}{2}$ -inch wall with 9 inches of refractory brick on the inside of the insulation would be amply strong and at the same time be very economical in fuel consumption.

Insulation of Kiln Bottoms and Flues

The volume of heat absorbed by the masonry work supporting the kiln floor and walls, the earth or artificial bottom on which this foundation is built and the flue from the kiln to the stack is not noticed and seldom gets any consideration. Without question there is a great loss of heat units, due to the conductivity of the materials on and of which the kiln is built. Also, the temperature of the gases in the stack flue, three to five feet from the kiln, average from 1100° to 1500°F depending on temperatures reached in the kiln. (Often the kiln is on light fire.)

Insulating materials have made marked savings when used in kiln structures above the ground, and also should serve as well when used to eliminate excessive flow of heat in the ground and foundations of kilns.

There should be other advantages besides the amount of heat units saved from soaking into the earth.

1. The time generally required to bring the ware, in the bottom of the kiln, up to a finishing temperature ought to be materially shortened.

2. The draft should be improved during the early portion of the burn as the stack temperature would be increased from heat units which formerly lodged in the kiln bottom or foundation.

Fuel Savings Due to Insulation

At present there are comparatively few kilns thoroughly insulated, yet many of these have been in service long enough to determine whether or not insulation pays.

Out of eleven plants using insulating material on their kilns, five report

a saving over 15%, some as high as 25%, while the balance report they do not know their exact saving in fuel, but estimate it around 15%.

Twelve plants, using it only on the crowns of kilns, report a saving of from 10 to 15%.

The kiln shown in Figs. 2 and 3 is burning on an average of 17% less fuel than the other kilns on the same yard. However, it has a few small changes in design which might be responsible for a part of the savings.

Exterior Crown Temperature Much Lower

The value of insulating kilns, however, is very obvious, regardless of whether fuel consumption records are kept. In the kiln under discussion for instance, the temperature of the crown was found to be approximately

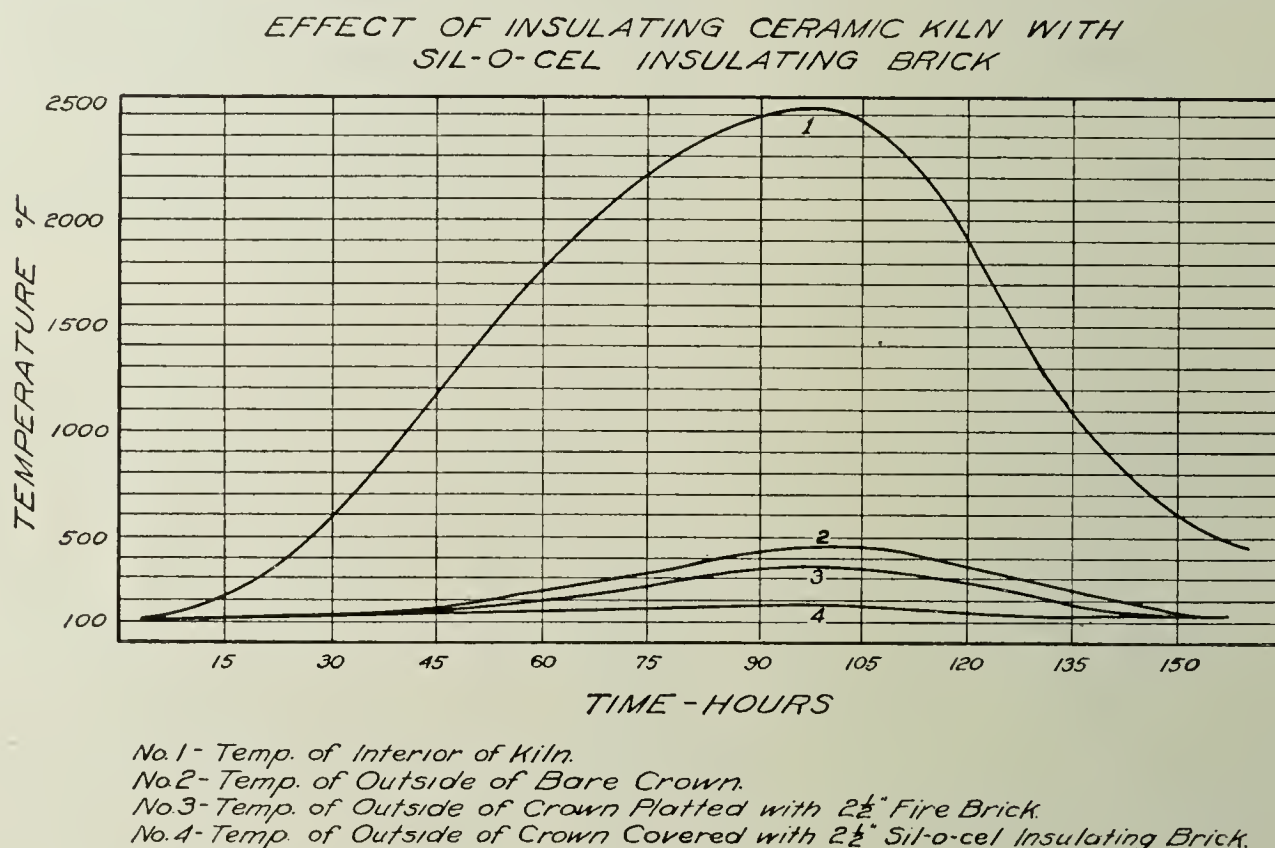


FIG. 4.

225°F less than the average of the uninsulated crowns on the same yard. The comparison in crown temperatures is indicated in the chart, Fig. 4.

Furthermore, it was found after several burns of this kiln that the total furnace area could be reduced about 10% and still have ample capacity to produce heat as fast as it could be absorbed by the ware.

These are all direct proofs of the value of insulating material.

Crown Construction

Because insulated kiln crowns have collapsed an unwarranted prejudice has developed. The crown is exposed to the highest temperatures and must be carefully built of a good quality refractory brick capable of carrying the load imposed on it without losing its form. In insulated kilns

the crown brick free themselves of the heat readily and seldom approach a state of vitrification where they are liable to fail, allowing the crown to fall. Where a good refractory is used there is no danger in insulating crowns and some crowns insulated are still in good condition after five or six years of use. The insulating brick, being light in weight, allow the crown free action in adjusting itself to expansion and contraction. Figure 5 shows the interior of a crown after it has been burned twelve times. The kiln is in excellent condition, showing no signs of failure. A high grade dry pressed brick was used.

Cost of Insulating

Because the initial price of insulating brick is somewhat higher than a high class fire brick, it has been considered by some as too expensive a material to use.

In covering the crown, there would accumulate the extra expense of laying the brick and perhaps a little extra care in putting on a good platting course over the insulators. The cost of insulating crowns, however, is repaid many times over. Take for instance, a kiln using 60 tons of \$5.00 coal per burn. A saving of 12% due to crown insulation is a conservative estimate and this would amount to \$36.00 per burn in this case.

The average uninsulated kiln walls are three to four feet in thickness. On a 30-foot round down-draft kiln there would be a saving in construction of a 22 $\frac{1}{2}$ -inch wall, approximately 32,000 common brick, plus the cost of laying. In the 27-inch wall the saving would be 24,000 common brick, plus the cost of laying (wickets and fire pockets not considered in these calculations). This saving in material and labor would go far toward making up the difference in first cost between an insulated and an uninsulated kiln.

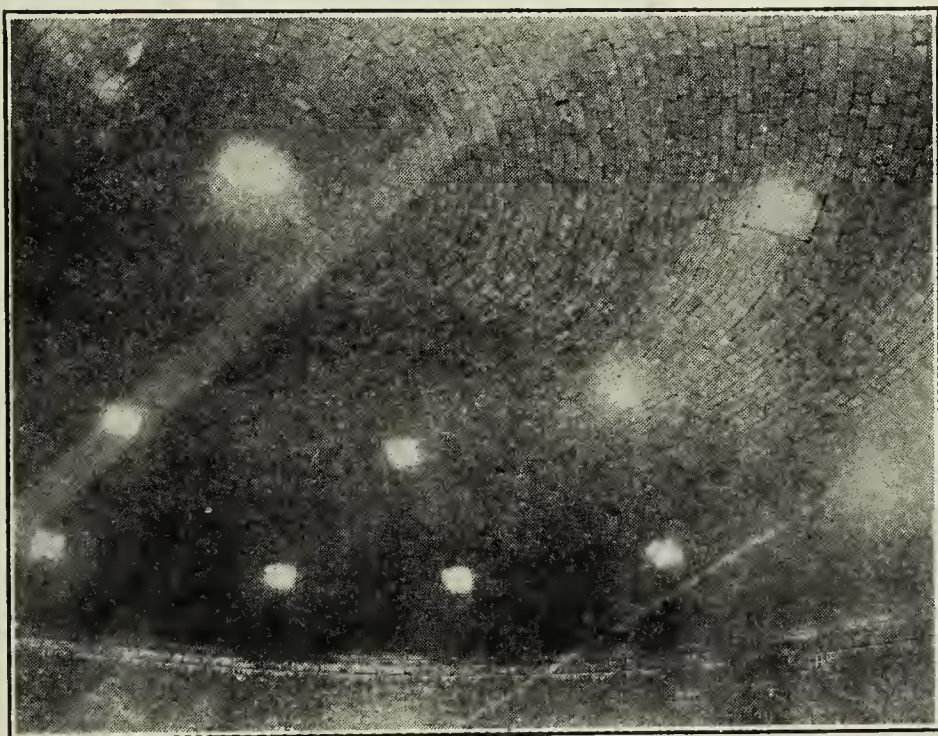


FIG. 5.

Different Forms of Insulation

Insulating material can be had in the form of brick or powder. The powder is somewhat cheaper than the brick and is ideally adapted for pack-

ing hollow walls and where no structural strength is required of the insulation.

An underburned silica brick has considerable insulating value, yet when properly burned their conductivity is somewhat higher than that of fire-clay brick. Their physical properties are such that they cannot be used in a periodic kiln lining or crown.

Insulating brick of an inferior quality can be made by mixing sawdust, coal slack or grain with the clay before burning.

Large Savings Possible throughout Industry

The value of insulating materials has been recognized for many years by other industries, such as oil refineries, steel mills, central power stations and gas plants, enameling and japanning, etc. Insulation has been practically a standard part of the construction of equipment used in these industries.

On a single yard, using 60 tons of \$5.00 coal per day, the saving would be \$16,425 per year and this indicates the enormous possibilities for savings throughout the entire industry.

A. P. GREEN FIREBRICK CO.
MEXICO, MO.

THE TRANSFER OF HEAT THROUGH REFRACTORIES AND ITS DETERMINATION

BY A. S. WATTS AND R. M. KING¹

ABSTRACT

This paper gives a review and bibliography of the literature on heat conductivity of refractories, as well as a description of a proposed method for the determination of the heat transmitting abilities of refractory materials. In the development of this method, standard apparatus, standard conditions, and standard operations were held as desirable and to a practical extent were obtained. It is believed that this method may be profitably used in testing and control laboratories for securing heat transfer data for refractory materials. The heat transfer values of several refractories, as determined by this method, are given and it is pointed out that this value closely approaches the resultant of all the forces which are acting to produce heat transmission.

Introduction

The importance of knowledge concerning the heat transmitting ability of refractories is recognized. Many methods have been devised with more or less conflicting results. An analysis of these various methods reveals that they differ only in detail. The general procedure has been to obtain in some manner the amount of heat that flows through a test piece of known area and thickness in a given time, and to obtain the temperature of each face of the test piece.

Review of the Literature.—The heat conductivity of various materials has been studied by many but mostly with materials other than refractories.

Pennock.—Probably the first work done on the heat conductivity of refractories was that of Pennock.² Cylindrical cores were cut. A combustion chamber was built in the center of a large steel drum and the space between the drum and the chamber was filled with glass wool. Four test cores were placed halfway between the bottom and the top of the drum at right angles on line of the diameters. One end of the cores extended into the combustion chamber and the other end extended outside the drum. The combustion chamber was heated with a blast lamp and the rate of temperature rise at the cold end obtained.

H. A. Wheeler.—The next work was by Wheeler.³ His methods were crude and results very inaccurate.

¹ The experimental data in this paper were obtained by the junior author in connection with the preparation of a thesis submitted by him to the Graduate School of Ohio State University in partial fulfilment of the requirements for the degree of Master of Science in Ceramics, June, 1923.

² J. D. Pennock, "Laboratory Notes on the Heat Conductivity, Expansion and Fusibility of Fire Brick," *Trans. Amer. Inst. Min. Eng.*, **26**, 263-9 (1896).

³ H. A. Wheeler, "Heat Conductivity of Refractory Clays," *Trans. Amer. Ceram. Soc.*, **6**, 119-40 (1904).

Fitzgerald and Hutton and Board.—Fitzgerald,¹ and Hutton and Board² in 1905 were not very direct and refined in their methods. The materials employed for the tests were in powdered form.

Clement and Egy.—The first extensive work done on refractory materials in fabricated form was by Clement and Egy.³ Heat was generated by a standardized coil, placed inside a hollow refractory cylinder. Heat transmitted through the walls of the cylinder was determined from heat input calculations. The temperatures employed at the hot face ranged from 400°C to 900°C.

Wologdine and Queneau.—At about the same time Wologdine⁴ and Queneau completed a still more extensive investigation at much higher temperatures and with a larger number of refractories. Small refractory plates were heated by means of a gas burner until equilibrium was reached. Hot face temperatures of 1000°C and 1350°C were employed. Thermocouple readings were taken at varying depths. The heat flowing through the piece was measured with a calorimeter. They found that permeability of a refractory to gases varied enormously with the temperature and pointed out that this should be taken into consideration with heat conductivity.

Nusselt.—In 1909 Nusselt⁵ used two concentric spheres with the powdered test material packed between. The inner sphere was of copper and heated with a platinum resistor. The outer sphere was of zinc. Temperatures were measured by thermocouples. The maximum temperature used was 600°C.

Hering.—In 1910 Hering⁶ recommended a test piece with no "lateral sides." He stated that a hollow sphere would make the ideal test piece, although impractical. He used a hollow cylinder open at one end, the closed end being rounded to a hemisphere. This was filled with a material which melted and kept molten at a fairly high temperature. This was done by means of heating coil. The test piece was immersed in a constant temperature liquid.

Fitzgerald.—F. A. J. Fitzgerald⁷ in 1912 worked under conditions more nearly approaching those of an operating furnace. A furnace was built

¹ F. A. J. Fitzgerald, "Heat Conductivity and Heat Insulating Materials," *Elec. & Met. Ind.*, **3**, 291-2 (1905).

² Hutton and Board, "Heat Insulation," *Jour. Soc. Chem. Ind.*, **24**, 802 (1905).

³ Clement and Egy, "The Thermal Conductivity of Fire Clay at High Temperatures," *Ill. Eng. Expt. Sta., Bull.* **36**, Aug., 1919.

⁴ Wologdine and Queneau, "The Conductivity, Porosity and Gas Permeability of Refractory Materials," *Elec. & Chem. & Met. Ind.*, **7**, Sept. and Oct., 1909.

⁵ Nusselt, "The Thermal Conductivity of Heat Insulators," *Engineering*, **87**, 1 (1909).

⁶ Carl Hering, "Thermal Conductivity," *Met. & Chem. Eng.*, **8**, 627-8 (1911).

⁷ F. A. J. Fitzgerald, "Experiments on Heat Insulation," *Jour. Amer. Electrochem. Soc.*, **21**, 535-44 (1912).

of the materials to be tested and heated by a nichrome resistor coil. The heat input was calculated from the power input, it being assumed that all heat going in was transmitted through the walls.

G. H. Brown.—In 1914 Brown¹ carried out an investigation under furnace conditions. Cylindrical test pieces, five inches in diameter and ten inches long, were placed in the wicket of a kiln so that one inch protruded on each side of the wall. The test piece was insulated from the wall by a bedding of kieselguhr. Holes were bored perpendicular to the axis, one inch from each end, and temperatures taken at these points by thermocouples. The rate of rise of temperature was determined.

Heyn.—Heyn² placed a test piece, in the shape of a brick, in the center of a wall of like material. A refractory plate was fitted against one side of this wall. This plate was heated by a granular carbon resistor furnace. Thermocouples were fitted at varying intervals in the test piece and the conductivity was calculated from the rate of rise of temperature.

Dudley.—In 1915, Dudley³ worked with a large furnace fired with coke. The heat passing through the walls was measured by a calorimeter of special construction. Readings were taken at 1000°C on the hot side after equilibrium was reached.

Dougill, Hodsman and Cobb.—It was also in 1915 that Dougill, Hodsman and Cobb⁴ published the results of an investigation of Wologdine except that a calorimeter of the guard ring type was used and the higher hot face temperatures were measured with an optical pyrometer. Conductivity is influenced by the porosity of the test piece, and when the pores are small, the radiation from wall to wall of the cavities is negligible at ordinary temperatures. A calculation showed that in pores of a size ordinarily found in refractories, the heat transmitted by radiation and convection was equal at 3910°Abs. or 3637°C. Another interesting comment of theirs was that heat transmission across a brick was dependent on the heat capacity of the material and that the thermal diffusivity may be of more importance than thermal conductivity. Thermal diffusivity was expressed as follows:

Thermal diffusivity = K/cs = the rise in temperature produced in 1 cc. of the substance by one calorie flowing in one second through one square centimeter of a layer one centimeter thick having a difference of 1°C between the faces.

¹ G. H. Brown, "The Relative Conductivity of Fire Clay and Silica Refractories," *Trans. Amer. Ceram. Soc.*, **16**, 382-5 (1914).

² E. Heyn, "The Thermal Conductivity of Building Materials," *Stahl. u. Eisen*, **34**, 832-4 (1914).

³ Boyd Dudley, "The Thermal Conductivity of Refractories," *Jour. Amer. Chem. Soc.*, **27**, 284-7 (1915).

⁴ Dougill, Hodsman and Cobb, "The Thermal Conductivity of Refractory Materials," *Jour. Soc. Chem. Ind.*, **34**, 465-71 (1915).

c = specific heat of material
 s = specific gravity of material
 K = thermal conductivity.

Roy A. Horning.—Roy A. Horning¹ described a method for obtaining heat transmission by the hot plate method.

An electric resistor unit was used, which covered a large area, and the amount of heat liberated over a small area in the center of the resistor measured. Between this resistor and the insulating material tested and in contact with the latter, a steel plate was placed. On the other side of the test piece was placed a hollow metal jacket through which water passed during the test. Temperature measurements taken with thermocouples within the area were considered the most representative of the entire heated area. It was decided that a small area at the center was less subject to errors, such as edge loss, etc. By this method both the heat input and heat output were measured, the former being measured by the amount of electrical energy used and the latter from the amount of water flowing and its rise in temperature.

Griffith.—Griffith² developed a method in which he used a molten metal bath to heat the hot face of the test piece at low temperatures, and a hot plate at the higher temperatures. Temperatures were obtained by means of thermocouples and the amount of heat transmitted was determined by means of a guard ring calorimeter.

R. D. Pike.—In a recent publication, Pike³ proposed the use of a conductometer. A standard test piece of known and another of unknown conductivity were placed in series, with all sides completely insulated. Heat was applied by means of a gas burner and the temperatures obtained by thermocouples.

Green.—The latest method for determining heat conductivity of which we have knowledge is that used by Green.⁴

His method presupposes: 1. The maintenance of an even and constant temperature on the hot face.

2. The accurate measurement of the rate of rise of temperature for any isothermal plane at a known distance from the hot face.

A wall was made of nine-inch brick of the material to be tested. These

¹ Roy A. Horning, "Methods of Making Thermal Conductivity Tests and the Transmission of Heat through Brick," *Trans. Amer. Ceram. Soc.*, **18**, 192–202 (1916); "Heat Transmission of Brick and High Temperature Insulating Materials," *Jour. Amer. Ceram. Soc.*, **3**, 865–76 (1920).

² Griffith, "The Thermal Conductivity of Materials Employed in Furnace Construction," *Trans. Faraday Soc.*, **21** (1, 2, 3), 192–206 (1917).

³ R. D. Pike, "Need for More Refractory Heat Insulators and Proposed Conductometer for Measuring Thermal Conductivity," *Jour. Amer. Ceram. Soc.*, **5**, 555–63 (1922).

⁴ Green, "The Thermal Conductivity of Refractory Material at High Temperatures," *Trans. Ceram. Soc.*, **21** [4], 394–410 (1921–22).

were placed so that their lengths indicated the direction of heat flow and the central brick of the wall was regarded as the test piece. The rate of rise of temperature was obtained at a specified distance from the hot face. Heat was applied to the refractory test piece by contact with a bauxite plate which was heated by a graphite resistor furnace. The results were calculated by the use of:

$$\frac{\theta_0 - \theta}{\theta_0} = \frac{2}{\sqrt{3.1416}} \int_0^{\frac{x}{2\sqrt{kt}}} \frac{e^{-B^2}}{B^2} dB$$

θ_0 = the temperature of the hot face.

θ = the temperature of an isothermal plane parallel to the hot face after a time t .

x = the distance of the hot face from the isothermal plane.

k = the thermal diffusivity of the material.

$B = 2\sqrt{kt}$

The thermal conductivity was calculated from the thermal diffusivity as follows:

$$k' = k \times c \times s$$

where

k' = the thermal conductivity

k = the thermal diffusivity

c = the apparent specific gravity

s = the specific heat.

There have been many publications other than those cited here which deal with the various theories of heat transfer and also the calculations

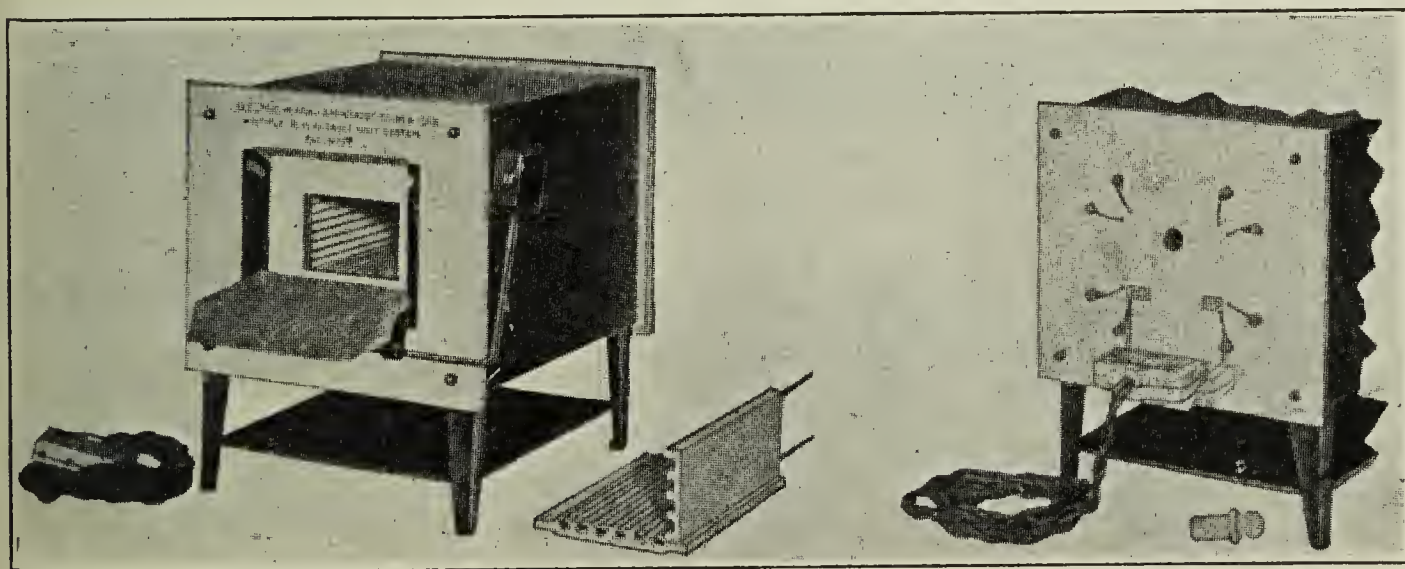


FIG. 1.—Back and front views of furnace.

involved. Notable among these are those of Langmuir and of Hering, which have appeared in the *Transactions of the American Electrochemical Society* and in *Metallurgical and Chemical Engineering*.

Classification of Methods: The methods reviewed may be classified in two general types:

A. The rate of rise in temperature in a refractory is measured. This involves the measurement of temperature and time.

B. The temperature of two surfaces, a given distance apart and the heat flowing from one surface to the other, measured.

The latter type has been more generally used.

The methods of securing data are:

1. The Hot Plate Method. A hot metal or refractory plate in contact with the surface of the test piece.

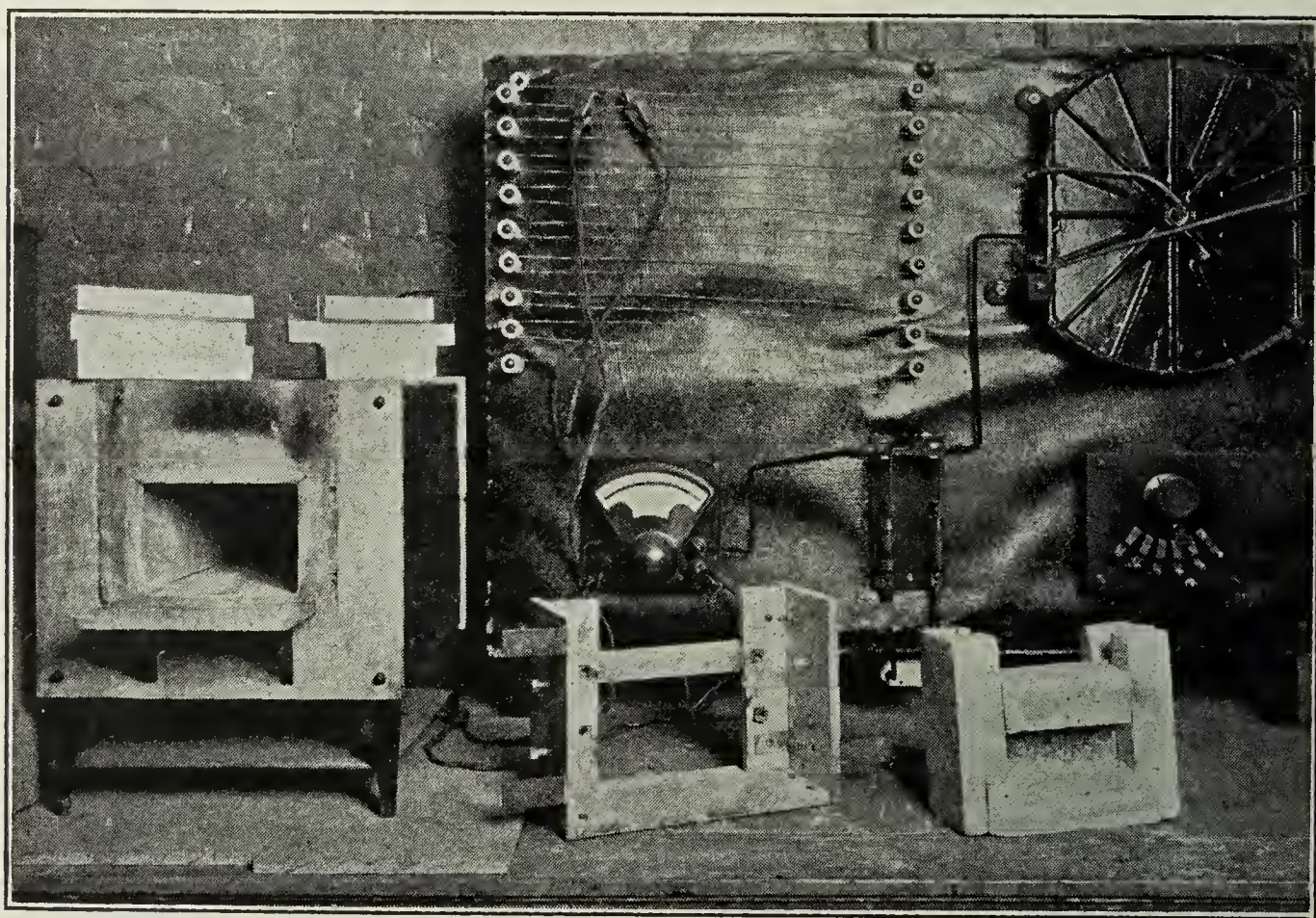


FIG. 2.—Furnace before assembling.

2. The Molten Metal Method. A bath of molten metal in contact with the surface of the test piece.

3. The Gas Chamber Method:

(a) Heat applied by means of a gas burner and against the test piece.

(b) Heat generated by means of an electric resistor coil and the test piece exposed to heated atmosphere.

The Investigation

Object of Investigation.—Need has been felt for a practical laboratory method for determining the heat transfer of refractories and this investi-

gation is an effort to supply this need. Refinements have been made consistent with this purpose and due consideration has been given to the cost of the apparatus.

Basic Assumptions.—Heat may be transferred by: (1) Conduction; (2) Convection; (3) Radiation.

It is recognized that the phenomena of absorption and emission have a marked influence on the heat transferring ability of a refractory. In other words, one refractory may absorb and concentrate more heat on the surface, and hence a temperature reading on a face of one might not be as representative of the true heat potential as would be a temperature reading on a face of another refractory. Also a given refractory may have less ability to emit heat from the colder surface.

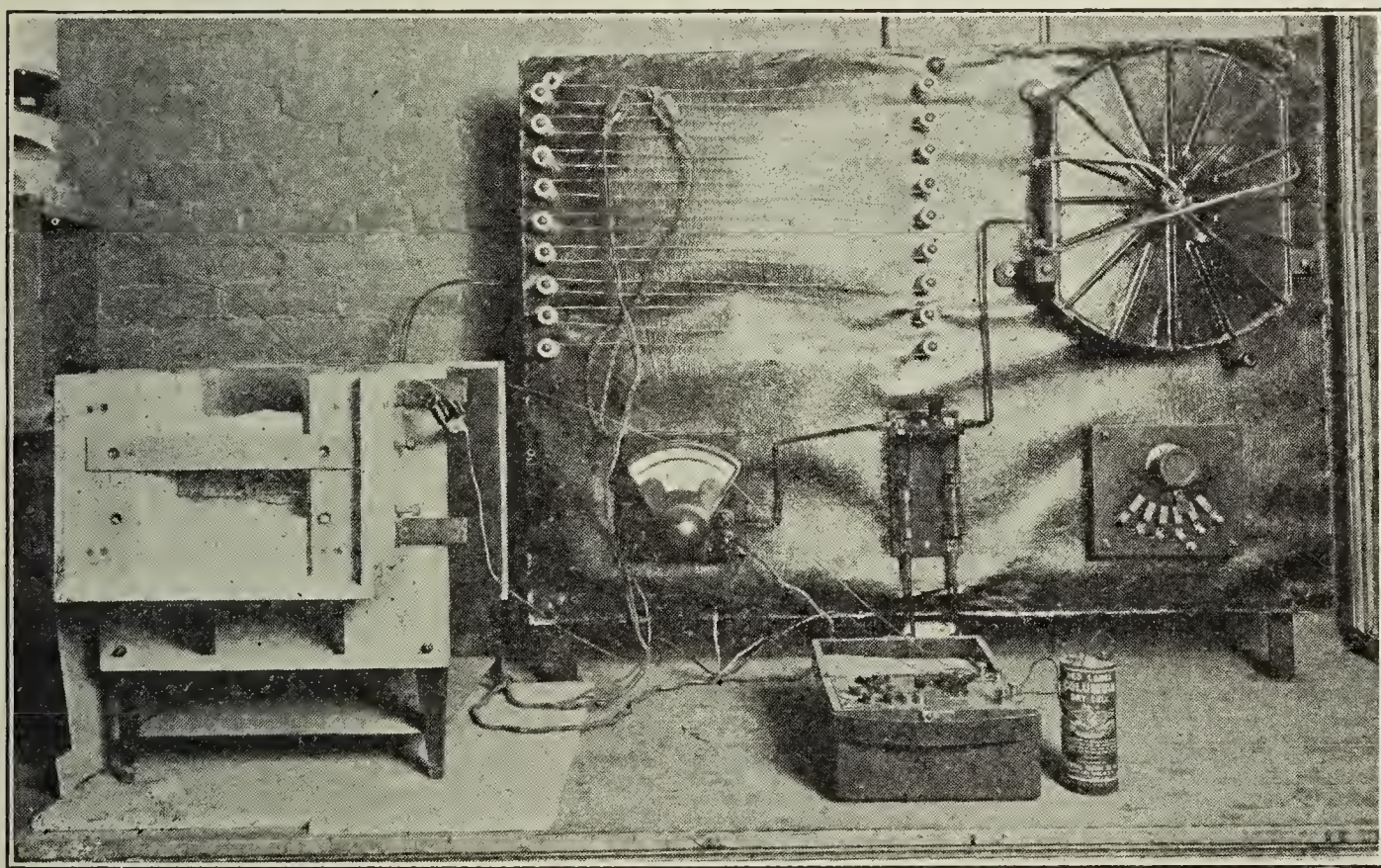


FIG. 3.—Furnace assembled.

The Preliminary Work.—The senior author began this investigation with determinations of the temperature gradient characteristic of the various refractories. Refractory splits were placed before the doorway of a Hoskins Type FB 204 electric furnace. Sil-O-Cel cleats were fitted over the ends and sides so as to cut down edge loss. The furnace was heated to the maximum attainable temperature, allowed to reach equilibrium and temperatures taken of the hot face exposed to the furnace atmosphere and of the cold face exposed to room atmosphere temperature. The temperature of the furnace was also taken two centimeters distant from the hot face to determine to what extent the contact couple was affected by the heat conductivity of the specimen.

This work was followed by similar but more refined investigations. The same furnace was used but the test pieces were placed in an insulating frame work made of Sil-O-Cel brick. (See Figs. 2 and 3.) Such a frame-work affords an insulation between the test piece and the furnace front and aids in cutting down heat losses around the edges and insures a flow of heat normal to the faces of the test specimen itself.

A sheet of asbestos $\frac{1}{16}$ inch thick was placed in front of the cold face of the test piece forming an air space about two centimeters thick. This cut down inaccuracies in readings due to drafts. Temperatures were obtained as in the previous study.

The results were expressed in terms of a standard. Hard steel, a high conductor, was first used as a standard and Sil-O-Cel an insulating material was used later. Results of these studies are given in relative values with those for fire-clay refractory as unity.

	First study	Second study
Fire clay.....	1.000	1.000
High SiO ₂ fire clay.....	0.974	1.070
Bauxite.....	0.937	0.925
Silica.....	0.875	0.900
Chrome.....	0.776	0.767
Magnesite.....	0.621	0.672
Firefrax (86% 2nd Grade SiC).....	...	0.584
Carbofrax A (100% SiC).....	...	0.452
Carbofrax B (92% SiC).....	...	0.409

The heat conductivity formula was not fully satisfied by the data obtained, as account had not been taken of the quantity of heat flowing through the test piece.

Observations and Calculations Used in Further Work.—The assumption is made first that the formula:

$$Q = K \frac{T - T'}{d} At$$

holds for heat conductivity, and second that the same formula holds for heat transfer, or

$$Q = H \frac{T - T'}{d} At$$

where H is substituted for K and is called the heat transfer constant.

T and T' were first determined for a refractory selected as a standard. In calculating results the formula was as follows:

$$Q = H \frac{T - T'}{d} At$$
$$Q = H_s \frac{T_s - T_s'}{d_s} A_s t_s$$

(s denotes values obtained on standard).

Then, if by the conditions of the test, we have,

$$\begin{aligned} Q &= Q_s \\ d &= d_s \\ H_s &= 1 \\ A &= A_s \\ t &= t_s \end{aligned}$$

We then have

$$1 = \frac{H (T - T')}{H_s (T_s - T'_s)} \quad \text{and} \quad \frac{H}{H_s} = \frac{T_s - T'_s}{T - T'}$$

The value H/H_s is the value sought.

If d and d_s differ appreciably, these values can be kept in the formulas and in this way make correction for the difference.

Apparatus.—(a) *Furnace.*—A standard, type 56 furnace, made by the Electric Heating Apparatus Company, was used.

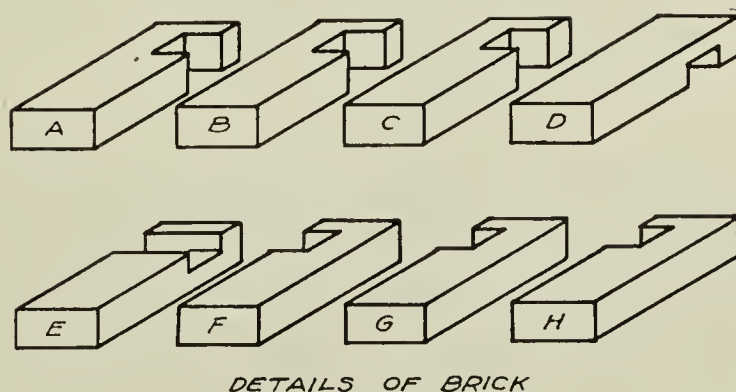
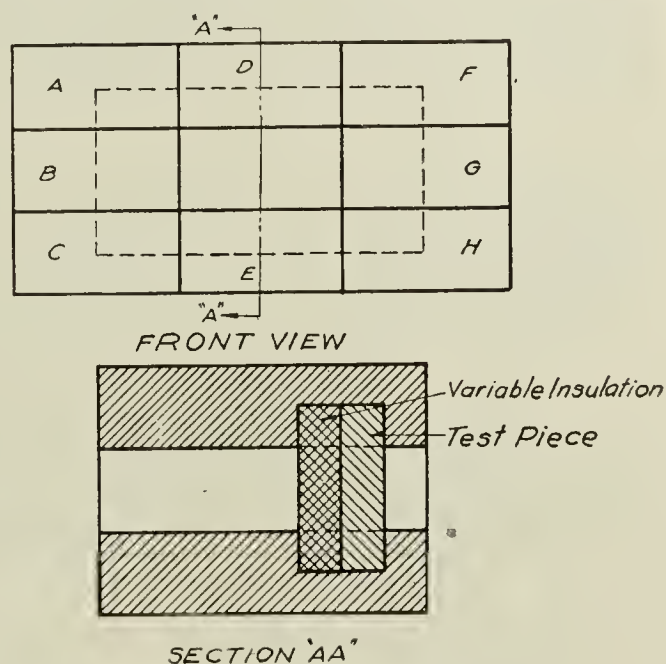
(b) *Thermocouples.*—Chromel-Alumel couples were used. No. 6 gage wire was used for the higher temperature measurements and No. 14 for lower temperatures.

(c) *Potentiometer.*—A Leeds and Northrup Indicating Potentiometer was used for temperature measurements.

(d) *Wattmeter.*—A Weston, Model 432 Wattmeter, 75/150 volts, 50/75 amperes, was used for measuring power input.

(e) *Insulating Front.*—This is shown in detail in Figs. 4, 5 and 6. It will be noted that this front is built up of raw Sil-O-Cel brick, Sil-O-Cel C-25 brick, and fire brick.

(f) *Cold Junction Box.*—This consisted of a block of Sil-O-Cel, 3 in. x 2 in. x 2 in., with a 1/2-inch hole bored in the center. The cold junction and the bulb of a glass thermometer were placed in this hole and powdered Sil-O-Cel packed around them. Different type of insulating front is shown in Figures



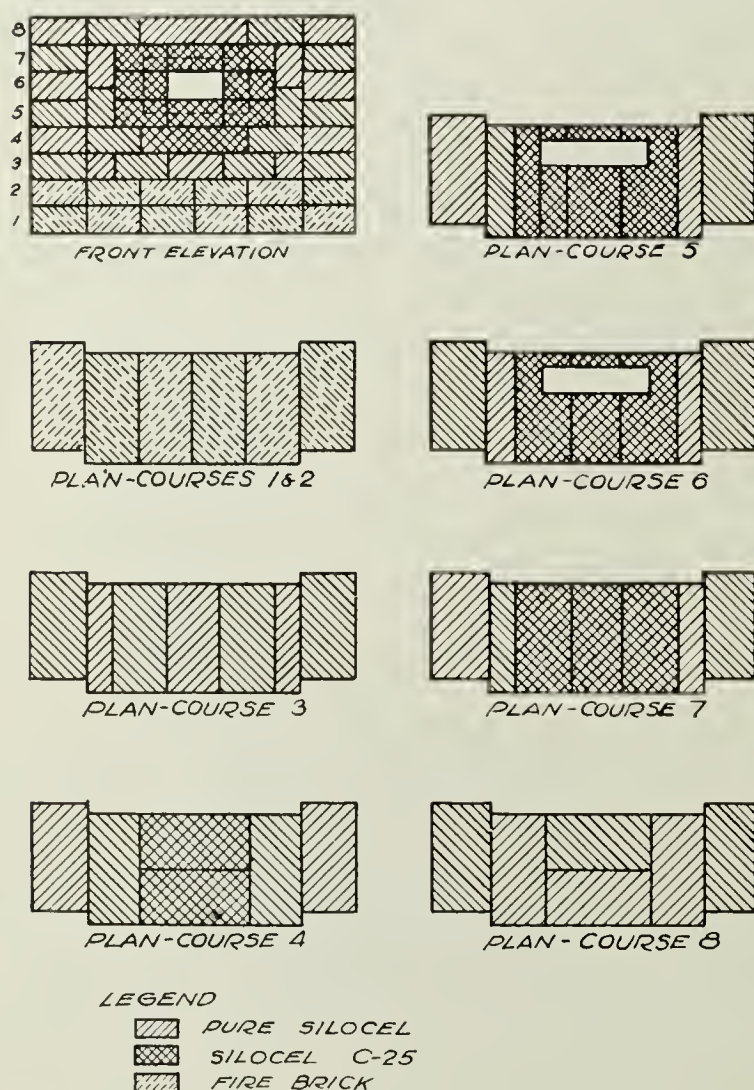
INSULATING FRAMEWORK

FIG. 4.

The cold junction and the bulb of a glass thermometer were placed in this hole and powdered Sil-O-Cel packed around them. Different type of insulating front is shown in Figures

4, 5 and 6, than is shown in Figures 2 and 3. This was the latest front developed and was found to be the most satisfactory.

Standardization of Conditions.—The value sought was H/H_s , where H is the heat transfer of an unknown material, and H_s is the heat transfer of a material selected as a standard. To get this ratio all the values in the heat conductivity formula previously given, except H , H_s , T' and T_s' , are held constant and the desired value calculated therefrom.



INSULATING FRONT

FIG. 5.

The main problem was to so control the power delivered to the furnace and to so adjust the insulation on the cold face of the test piece, that the test setting will have the same cold face temperature as well as the same hot face temperature from test to test.

A Sil-O-Cel block, cut to the size of a refractory split, was fitted in the pocket of the insulating front, Sil-O-Cel powder being used to pack into all free spaces at the edges where heat might be lost.

A thermocouple was placed in contact with the hot face of the test piece by bringing it through the back of the furnace and suspending it at the front by means of fine crossed nichrome wires. A second couple was placed in contact with the cold face

by threading it through the Sil-O-Cel walls of the insulating front. (See Fig. 6.) A third couple was brought through the back and the end placed near the center of the furnace. This couple was for the general purpose of obtaining the temperature of the furnace.

A sheet of asbestos $1/32$ inch thick was placed in contact with the cold face of the test setting and the bulb of a glass thermometer was pushed tightly against this sheet of asbestos to determine the temperature at this point.

The furnace was then heated until equilibrium was reached and maintained for an hour with a hot face temperature of $1000^{\circ}\text{C} \pm 10^{\circ}$. Readings were recorded at the beginning and end of the hour.

A carborundum (Carbofrax B) split was placed in the setting and after some adjustment it was found necessary to place a block of Sil-O-Cel two centimeters thick against the cold face of the test piece, in order to secure the same temperature and power conditions used in the case of the Sil-O-Cel. In order to have identical radiating surfaces at the cold face of the setting, a sheet of asbestos $\frac{1}{32}$ inch thick was placed in contact with this face.

The furnace was thus standardized with materials which represent the extremes of the conductivity scale for refractory materials. It was also demonstrated that an insulation, equivalent to two centimeters of Sil-O-Cel, represents the insulating difference between the extremes.

The ideal way to test additional refractories would be to place them in the setting and adjust the insulation by varying the number of thin

blocks of Sil-O-Cel or some other insulating material, placed against the cold face of the test piece until the prescribed conditions of temperature

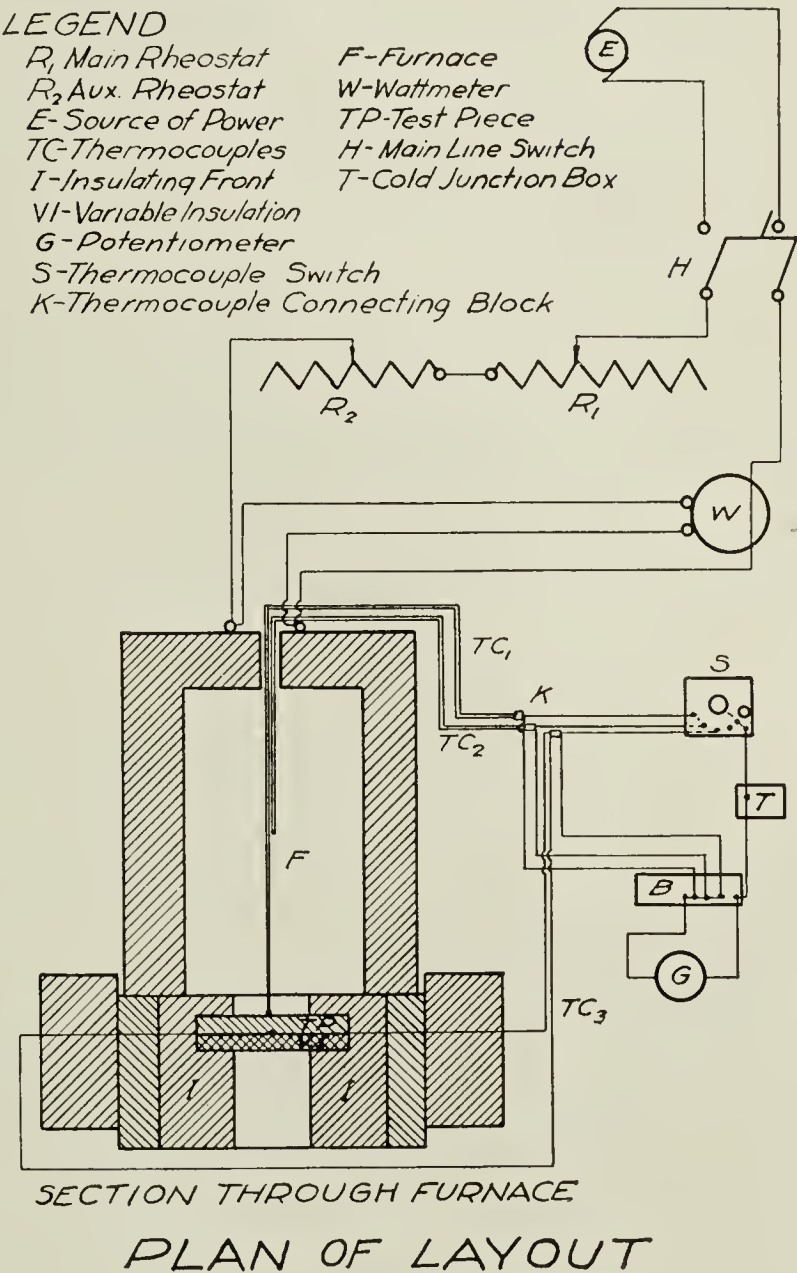


FIG. 6.

TABLE I

Refractory	Sil-O-Cel	Carbofrax B (92% SiC)	Mag- nesite	Alundum	
Hot Face Temperature T	1012	1009	1004	1011	1017
Cold Face Temperature T'	348	954	924	836	841
T - T'	664	55	80	175	176
Cold Face Temperature Test Setting	258	264	249	257	245
Cold Junction Temperature	40	37	37	36	28
Power in Watts	2150	2150	2150	2150	2150
Right Side Temperature of Furnace	147	147	151	155	153
Left Side Temperature of Furnace	158	159	163	163	168
Bottom Temperature of Furnace	197	185	209	198	205
Top Temperature of Furnace	236	238	243	243	247
Back Temperature of Furnace	215	218	223	223	228

and heat flow are obtained. Since thin pieces of Sil-O-Cel are not easily procurable, it was necessary to resort to the use of thin sheets of asbestos over the Sil-O-Cel block.

For a magnesite split, one centimeter of Sil-O-Cel and fourteen sheets of $1/32$ -inch asbestos were necessary to secure standard conditions.

In Table I are the data obtained while standardizing the equipment and conditions.

Heat Loss Calculations

It will be noted that, for practical purposes, the temperatures obtained from test to test are in close agreement. However, a correction can be made for the difference in heat lost by the use of basic formulas for radiation and convection. The Stefan-Boltzmann Radiation Formula is as follows:

$$C = K(T_1^4 - T_2^4)$$

where

C = the total heat radiated

K = a constant depending on the units used

T_1 = absolute temperature of the hot body

T_2 = the absolute temperature of the cold body.

Since we use the same surface, units, etc., from test to test we can for our purpose consider $K = 1$.

Therefore, to get the ratio of heat radiated in a test of an unknown material to the heat radiated in the test of the standard material, we have:

$$\frac{C}{C_s} = \frac{T_1^4 - T_2^4}{T_{1s}^4 - T_{2s}^4}$$

Values with s subscript are obtained with standard.

Example.—Assume the temperature of the cold face of the setting for the standard material to be 260°C and the air surrounding it to be 240°C , and the corresponding temperatures for the “unknown” setting 255°C and 235°C .

$$\text{Then } \frac{C}{C_s} = \frac{(273 + 260)^4 - (273 + 240)^4}{(273 + 255)^4 - (273 + 235)^4} = \frac{533^4 - 513^4}{528^4 - 508^4} =$$

$$\frac{11,487 \times 10^6}{11,277 \times 10^6} = 1.02$$

The equation used for convection is:

$$R = k(t - t')$$

where

k = a constant

t = the temperature of the hot body

t' = the temperature of the cold body.

Then from the above reasoning and example, we have

$$\frac{R}{R_s} = \frac{k(t - t')}{k(t_s - t_s')} = \frac{260 - 240}{255 - 235} = \frac{20}{20} = 1$$

Experiments with Possible Standards.—This investigation has not yet yielded a material which can, with certainty, be chosen as a dependable standard. Such a material must be able to stand repeated heatings to 1000°C without losing its homogeneity, and it must be reproducible in all properties. Experiments on raw Sil-O-Cel show that this material cracks, splits and checks. Some tests were made on alundum splits. The tests indicate that this is a promising material for a standard. Additional tests will be made.

Using alundum specimen No. 1 as a standard and the data given in Table I we have the following heat transfer values.

	1	Alundum 2	Sil-O-Cel	Carbofrax B (92% SiC)	Magnesite
$\frac{H}{H_s} =$	1.000	0.977	0.263	3.39	2.33

Summary and Conclusion

1. A review of the literature on the subject of heat conductivity has been made and the various methods used have been described and classified.
2. The principles, factors and forces which influence the transfer of heat through a material have been discussed.
3. The story of the development of the proposed method has been related.
4. The apparatus used in the method has been described in detail.
5. A detailed description of the procedure of carrying out a test has been given.
6. Calculations to secure refinements in results have been carried out.
7. The method developed for determining the heat transfer of refractories can be used as follows:
 - (a) For determining the relative heat transfer of refractory materials with commercial accuracy.
 - (b) For determining the temperature gradient of refractories for any desired cold face or hot face temperature up to 1000°C for the hot face temperature. Test pieces of any thickness may be used up to the thickness of a standard straight.
 - (c) For determining the effect of various thicknesses of insulating materials on the temperature of a refractory.
 - (d) For determining the effect of various coatings, and effect of color and texture of surface on the temperature gradient, and heat transfer of the refractory.

(e) For the determination of the rate of heat penetration of a refractory.

NOTE: Acknowledgment is made of the many helpful suggestions given by J. Spotts McDowell.

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METALLURGICAL REQUIREMENTS OF REFRACTORIES

For Use in the Aluminum Industry¹

By ROBERT J. ANDERSON²

Introduction

So far as can be learned, the question of refractories for use in the aluminum industry has been neglected considerably, but this matter is of the greatest importance to the producers of primary aluminum and to manufacturers who melt aluminum and aluminum alloys. The question of refractories for use in the aluminum industry will be discussed only briefly here, but refractory makers can get further information as to the needs and requirements of users by consulting with the Non-Ferrous Metals Section of the Bureau of Mines. In taking up discussion of the subject here, it is convenient to discuss (1) refractories for use in melting substantially pure aluminum, and (2) refractories for use in melting aluminum alloys, as is done below.

At the outset, it should be pointed out that refractories for use in aluminum and aluminum-alloy melting furnaces should be considered from two different points of view: (1) refractories for the setting of the furnace itself, and (2) refractories to be used as the containing vessel or in a hearth with which the aluminum or aluminum alloys are in contact. It should be pointed out also that while the temperatures employed for melting aluminum and aluminum alloys are relatively low (below 800°C usually), the corrosive action of liquid aluminum and its light alloys is great, and refractories fail in aluminum melting (where the liquid metal is in contact with the refractory) by corrosion or eating away of the refractory.

Refractories for Aluminum Melting

Referring first to the production of primary aluminum by electrolytic reduction, the material used for the furnace linings is carbon, such as petroleum coke or gas carbon. In making a furnace for aluminum reduction, a steel shell is lined first with any suitable refractory which has low thermal and electrical conductivity, and within this lining a layer of rammed lining of petroleum coke is placed. The problem of obtaining a good lining for aluminum reduction furnaces at low cost is one of importance, as is the problem of making electrodes for this work. Petroleum coke is expensive, and a source of cheap high grade carbon, very low in ash, is desired by the aluminum industry.

Aluminum from the reduction cell is remelted for pouring into pigs or rolling ingots in the plants of producers. The melting is carried out usually in furnaces of the reverberatory type, in which fire brick is used

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for the hearth. Silicon and iron are taken up by liquid aluminum from such hearths, with resultant contamination of the metal, and since no refining can be done with aluminum as is the case with most other metals, it is desirable to eliminate contamination wherever possible. The Baily electric furnace, with a lining of fire brick for the hearth, has been used for melting the aluminum reduction-cell product.

In aluminum rolling-mill practice and in wire drawing and other fabrication of the substantially pure metal, the aluminum is melted in furnaces of various types, but usually in reverberatories or other furnaces where the liquid metal is in contact with the refractory, for pouring into ingots. The principal refractory so far used in furnaces for such melting has been high-grade fire brick. The requirements of a refractory to be used in a furnace where the liquid metal is in contact with the refractory are: (1) the property of withstanding temperatures up to 850° or better 900°C ; (2) the property of withstanding the corrosive action of the liquid aluminum; (3) the property of withstanding temperature changes without cracking or spalling; and (4) mechanical strength to withstand blows which arise when cold pigs of metal are thrown against the refractory. The same properties are required in refractories against which light aluminum alloys are melted. In melting high grade commercial aluminum for subsequent drawing into wire, for electrical purposes, it is essential to prevent contamination of the metal by impurities which would lower the electrical conductivity of the wire.

Refractories for Aluminum-Alloy Melting

Aluminum alloys are melted for fabrication into sheets, rods, and shapes; for the production of castings in foundry practice; and for the production of castings in die-casting and permanent-mold-casting practice. Referring first to the production of ingots of aluminum alloys for subsequent working, the total amount of fabricated alloys produced is small, and the alloys used principally for fabricating include the following: Duralumin, for rolling, drawing, forging, and extruding; 98.5:1.5 aluminum-manganese alloy for rolling into sheets; certain aluminum-copper alloys for forging, as well as aluminum-copper-manganese alloys; and some aluminum-zinc alloys for drawing and rolling. The alloys are melted in a variety of furnaces, but chiefly in iron-pot furnaces or in crucible furnaces, unless the production is large when reverberatory-type furnaces are employed.

It is in light alloy foundry practice that the greatest variety of furnaces is employed, and if the refractory situation as regards furnaces for foundry practice can be solved satisfactorily, considerable progress will have been made. For founding, aluminum alloys are melted in the following types of furnaces at the present time: coal-, coke-, gas-, and oil-fired reverberatories; oil- and gas-fired stationary and tilting iron-pot furnaces;

coal- and coke-fired, natural- and forced-draft pit furnaces, using a crucible; oil- and gas-fired stationary and tilting crucible furnaces; oil- and gas-fired open-flame tilting and rotating furnaces; and two or three kinds of electric furnaces. The iron-pot furnace is the type favored by foundrymen.

In the case of large reverberatory furnaces, the refractory is usually fire brick, and these furnaces are useful where the foundry capacity is large, and where large scrap, such as crankcases, is melted. Stationary cylindrical furnaces of the new Schwartz type have been installed at two or three foundries, and at one plant zirconia is to be tried for the refractory. In the case of iron-pot furnaces, the shell is lined with fire brick, and the alloy is melted in a cast-iron vessel. The cast iron is usually ordinary grey foundry iron, but some pots are made of a mixture of 40% semi-steel and 60% Southern foundry iron. Pots of this type fail by stretching, scaling, and fissuring, and the average life is only about 40 heats. Cast-iron pots also cause contamination of the aluminum alloy with iron, and they are not suitable for melting some alloys. Cast-iron pots are readily eaten away by liquid aluminum-zinc alloys, and they are not good for melting duralumin because iron is introduced. Graphite-clay crucibles are used in pit furnaces and in crucible furnaces as the containing vessels. Such crucibles are more readily attacked by aluminum alloys than by brass and bronze. Makers of crucibles state that they have a special clay-graphite mix for crucibles to be used for aluminum-alloy melting, and information on this subject would be useful to foundrymen. Not a large amount of aluminum alloys, as referred to the total output, is melted in crucible furnaces, but in most small foundries pit or crucible furnaces are employed for melting.

In some foundries, open-flame tilting or rotating and tilting furnaces are employed for melting. Fire brick and rammed ganister linings are employed. In one plant, the rammed ganister lining has been exceptionally good, as much as 2,000,000 pounds of alloys having been melted with one lining in a 36-inch furnace. Electric furnaces are employed in a few foundries for aluminum-alloy melting, and the refractory is usually fire brick.

The question of refractories and containing vessels for liquid aluminum alloys in die casting and permanent-mold casting is important. In the case of die casting, the problem has never been satisfactorily solved, and research on the subject is required. For die casting, the alloys are made up in a melting furnace, the iron-pot furnace being favored, and cast into small pigs preparatory to delivery to the die-casting machine. In casting, the liquid alloy is contained in a small iron pot, the temperature of the alloy being about 700° to 750°C, and is forced into the die by air pressure. A submerged nozzle of cast iron is suspended in the alloy, and this conveys

a charge of liquid alloy to the die plate opening; air pressure then forces the alloy into the die. Cast iron is used both for the holding pot and for the nozzle, and the dissolution of iron is high. When running aluminum-copper alloys with the desired composition of 8 to 10% copper and remainder aluminum, the iron content generally runs up to 3%. This gives rise to difficulty on polishing die castings because of the formation of the hard intermetallic compound Fe Al_3 which stands in relief on buffing. Alundum has been used as a lining for die-casting pots and as a lining and covering for nozzles, but this has not been successful.

The question of linings in secondary smelting practice for aluminum and aluminum alloys is of special importance; the life of linings in furnaces for smelting is low because of the local effects of burning. Reverberatories, crucibles, and iron pots are used in secondary practice, and the requirements of a refractory for secondary smelting are more severe than in simple melting. As is known, aluminum oxidizes readily and rapidly with increasing temperatures, and at the temperature of smelting, particularly with borings and some drosses, a thermit-like reaction occurs. This is very destructive of refractories and linings. Moreover, in smelting, fluxes of various kinds are employed, and certain of these are destructive of refractories.

Available Information and Work in Progress

Preliminary study of the refractory question as applied to aluminum-alloy melting has been made by the present writer, in connection with a study of melting practice for aluminum and aluminum alloys.¹

Since the dissolution of impurities by liquid aluminum and aluminum alloys is serious in the case of linings, suggestion has been made at various times that the following refractories should be examined with a view to determining their suitability: alundum, carborundum, magnesia, bauxite, zirconia, sillimanite, spinel, and other super-refractories, and research in connection with these refractories, or at least a collection of the available information, would be valuable.

At the present time, the Bureau of Mines is making a study of materials for use as refractories and containing vessels for melting aluminum alloys in die-casting practice. Many refractories, irons, steels, and special alloys are to be examined as to solubility in liquid aluminum alloys, and the Bureau will be glad to cooperate with refractory makers in testing the suitability of refractories in connection with this work.

¹ Cf. R. J. Anderson, "Aluminum Melting Practice," *Foundry*, **50**, 737-741, 792-797, 823-826, 866-870, 919-924 (1922); "Aluminum and Aluminum-alloy Melting Furnaces," *Trans. Amer. Foundrymen's Assoc.*, **30**, 562-604 (1923); "Iron-pot Melting Practice for Aluminum Alloys," *Metal Ind.*, **19**, 189-190, 246-247, 285-287, 360-362, 397-399 (1921); *ibid.*, **20**, 60-61, 309-311 (1922).

THE REQUIREMENTS OF FIRE BRICK SUITED TO MALLEABLE PRACTICE¹

BY H. A. SCHWARTZ AND A. F. GORTON

The purpose of the present paper is to present as briefly as possible an outline of the service requirements of fire brick in the malleable industry.

A malleable foundry uses fire brick for two principal types of equipment; annealing furnaces and melting furnaces. Although the construction of an annealing furnace requires very considerable quantities of brick, the life of this unit is usually so long that the requirements of brick in the annealing department of a malleable foundry are relatively insignificant in quantity as compared with the brick requirements for melting furnace linings.

Although some open hearth malleable is made, and although some plants still produce cupola malleable, current melting practice in the industry involves the use of the air furnace.

The still more modern electric melting methods are not of interest in the present connection since they do not involve the use of furnaces lined with clay brick. A discussion, therefore, of the life and service of fire brick in air furnaces is virtually also a discussion of the refractory requirements of the industry at least in so far as quantity requirements are concerned.

In general, brick may fail from any one of a number of causes. Among the principal types of failure the following may be mentioned: by melting, by spalling, by fluxing, by erosion, by changes of shape, or warping, and by deformation under load.

Not all of these are of importance in air furnace practice, and the relative importance of the several causes of failure is different in different parts of the same air furnace. Unfortunately, few malleable foundrymen and not all manufacturers of fire brick recognize this fact, and there still remains a tendency to make one kind of fire brick resist all of the several causes of failure when much better practice would result if different characters of refractory were employed at different places in the furnace.

An air furnace, as is well known, is a furnace of reverberatory type consisting of a long, rather narrow and quite low hearth, into which flame from a fire box is introduced at one end, and from which the flame escapes to the stack at the other end. The roof of the furnace is made in removable sections called bungs, and when one heat has been run out, certain sections of this roof are removed and the melting stock required for the next heat is introduced, usually by hand, the roof replaced, and the next heat begun. Very generally the furnace is idle during the night and over the week end.

The molten charge may have a temperature of some 2500° or 2700°F when ready to pour. The temperature of the flame, and hence of the roof

¹ Presented before the Refractories Division, Pittsburgh Meeting, Feb., 1923.

against which it impinges may perhaps be taken as being some 3200° or 3400°F .

During the process of melting a considerable amount of metallic iron is oxidized and combines with silica derived either from the sand bottom of the furnace or from the clay brick side wall to form a slag of approximately the following composition: FeO , 29%; Fe_2O_3 , 1%; MnO , 5%; Al_2O_3 , 15%; SiO_2 , 50%.

The relatively constricted cross-section of the furnace at the bridge walls at each end of the hearth, and more especially at the rear bridge wall, produces very considerable velocities of flame at these points. It will be obvious from these considerations that the air furnace presents at different parts of its structure opportunities for several of the types of failure previously referred to.

In the fire box the brickwork is exposed to the formation of clinkers from fusible coal ash and the removal of these clinkers between heats may result in considerable mechanical damage to the brick. The furnace roof and the side walls, more especially near the fire box end of the furnace, are exposed to very considerable temperatures. The side walls at the slag line are exposed to the chemical action of the slag or, more properly speaking, to the chemical action of molten iron oxide which later is converted into the more complex acid slag already alluded to.

The furnace roof is exposed to rather rapid and severe changes of temperature which in turn is conducive to spalling. In the furnace neck, that is, in the passage from the rear bridge wall to the stack, the working conditions are usually not severe, and brick lasts a considerable time.

The possibility of failure due to the warping of the wall under heat must here be taken into consideration, although in the furnace proper, such failures do not in general occur, being overshadowed by the rapid destruction of brick from other causes.

Since air furnaces are very low, the side walls being seldom over three or four feet high above the slag line, and since the roof load hardly amounts to more than 500 pounds per running foot on each side wall, failures due to the deformations under load are not encountered. They might be expected to occur at the base of very high stacks, but in the writer's experience at least, this difficulty has either been very rare or non-existent.

In general, furnace side walls have to be replaced at least at the front end of the furnace where the service is most severe, once in two weeks. The roof is, of course, replaced only as required, by removing the bungs which have outlived their usefulness, and putting on new ones.

The consumption of fire brick in the roof and side walls of an air furnace is about equal, expressed in terms of number of brick used in a given unit of time.

Reviewing the working conditions of the furnace, we are led to conclude

that bung or roof brick must be of a character to resist high temperature and rather severe and rapid changes of temperature. In so far as the user's experience is of value, this seems to us to mean that bung brick must be made of a refractory clay, and must be ground, pressed, and burned so little that the resulting product is porous enough to resist changes of temperature and spalling.

It may be that the character of service required could be given by a properly made hard, dense, brick, but a satisfactory bung brick of this character has not so far come under our observation. Silica brick, in spite of its refractory character, is totally useless on account of its great sensitivity to changes of temperature.

The upper part of the side wall is exposed to service similar in character, though, perhaps, less severe than that of the roof. The lower part of the wall, however, being exposed to the action of molten slag, fails almost altogether by chemical action or fluxing.

Since the failure of the wall at the slag line entails replacing it throughout, the requirements for side wall brick are determined by service requirements at the slag line. It is thus indicated that side wall brick should be chemically inert and very dense in order to prevent slag penetration. It must, of course, in addition be reasonably refractory, although this requirement is not quite so important as it is in the furnace roof, since at, and below the slag line, where failure actually does occur, the temperatures are not as high as at the top of the furnace.

The use of chrome brick on account of its neutral properties seems obvious. Beside its high cost a further objection is the possible reduction of chromium by the carbon of the metal. Chromium is metallurgically detrimental in malleable iron.

At the points in the side wall where the bridge walls abut, erosion due to the rapid passage of flame is likely to occur. It would, therefore, seem advisable to make this part of the wall, also, of a very dense brick as was indicated for slag resistance. Erosion, however, is limited to a very few brick, and therefore, is not economically important.

The total brick consumption in the lining of the neck and stack of a furnace is not high, owing to the relatively long life of these portions of the structure. We have not, thus far, had opportunities of determining what factors in practice make for long service under these circumstances. As previously indicated, the requirements are mainly that the brick shall not fail by warping or under load.

It would seem that a brick which makes a satisfactory boiler setting and stack should serve also under the present circumstances provided its refractoriness was sufficiently high to withstand temperatures around 2500°F continuously.

It may not be uninteresting to note in passing, that, as in most other

applications of refractories, a furnace which is operated continuously day and night is a larger consumer of brick than one which cools off during a portion of the twenty-four hours. This doubtless arises from the fact that when the furnace is operated part time only, the wall never gets heated completely through. The outer layers then operate as a means of cooling the inner ones, and also remain in better condition to withstand mechanical loads than when they become thoroughly heated toward the end of a continuous week's run.

The use of basic refractories in air furnaces does not seem to promise any advantages to offset the obvious disadvantages in cost, resistance to temperature changes, slaking, etc. So far as we know these considerations have justly prevented even their experimental use.

The ultimate purpose of this superficial discussion has been to bring forward in the minds of the producers of refractories the fact that one kind of brick cannot be expected to meet perfectly the requirements at every part of an air furnace, and to stimulate in the minds of the manufacturers of refractories, attention and study of the several requirements in order that, if possible, suitable brick specialties may be developed, calculated to withstand in the highest degree, the service conditions imposed by practice in the several portions of such furnaces.

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PROGRESS REPORT ON SPECIFICATIONS FOR REFRACTORIES¹

By R. F. GELLER²

ABSTRACT

Following a conference with producers and consumers of refractories, a series of proposed laboratory tests were conducted on forty-one commercial brands of brick. The work included reheating at 1450° and 1400°C, quenching, load test, fusion point determination, chemical analyses and petrographic examination. Results of tests are presented. They will be more fully discussed when correlated with service tests now under way.

Introduction

Organization and Object.—On March 8, 1922, at the Bureau of Standards in Washington, a conference was held. W. A. Hull presided as chairman. Producers and consumers of refractory brick were present as an advisory board. The object was to establish specifications to be used by the various government departments when purchasing refractories for government use. The thought was that these specifications might ultimately be adopted by the trade.

Refractories for Boiler Setting.—Tentative specifications and tests were first prepared for refractories to be used in stoker-fired boiler settings. The Committee was not unanimous as to the value of these tentative specifications, hence it was decided to apply the tests to a representative number of recognized first quality refractory brick; correlate the data obtained with records of the behavior of these several brick under service conditions, and present the combined results to the advisory committee for their consideration.

Field Test.—With the aid of E. B. Powell, of Stone and Webster, brick were submitted to the Bureau of Standards from sixty power plants, representing all of the important industrial districts of America. Some of the shipments were duplicates but the final count showed forty-one different brands of standard nine-inch brick. Active work on the testing of these brick was started in June, 1922, and completed approximately one year later. The following is a report of the test methods followed and the results obtained.

Methods

Following the practice of the Navy, it was decided to establish (a) suitability tests, whose function it is to determine whether or not a brick can meet the requirements; and (b) control tests which are to serve as a check on separate shipments.

¹ Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

² Received Sept. 4, 1923.

The following tests were suggested by the Committee and adopted:

Suitability tests

- a. An endurance test
- b. A constant volume test
- c. A quenching test

Control tests

- d. A fusion point test
- e. A load test

Suitability Tests

Endurance.—The endurance test is applied in two ways: 1. The brick is placed on end in a gas-fired furnace and subjected to a temperature of 1450°C for 72 hours. Two bricks of each brand are used in this test.

2. The brick is laid flat, supported at the ends leaving seven inches clear span, loaded at the center with a brick cut to weigh five pounds, and subjected to a temperature of 1450°C for 72 hours. Two bricks of each brand are used in this test.

Constant Volume.—The constant volume test consists in subjecting a brick to a temperature of 1400°C for five hours. Seven bricks of each brand are used in this test.

Quenching.—The quenching test is conducted on brick which have been reheated at 1400°C for five hours. The advantages of this preheating, have been discussed by Howe¹ and it is recognized that it produces decidedly better comparative results. The quenching itself followed in principle the tentative A.S.T.M. method. It was carried out by heating the brick at one end in a kiln door and plunging them half way into running water. The brick were allowed to remain in the water for three minutes, taken out, allowed to steam in the air for five minutes and then returned to the kiln door. This was repeated in hourly cycles until the brick lost a specified amount. Three kiln temperatures were used, viz., 850°C, 1100°C, and 1350°C, and five bricks of each brand were quenched from each temperature.

Control Tests

Fusion Point.—The fusion point test was made according to the standard A.S.T.M. method.

Load Test.—The load test was carried out according to the standard A.S.T.M. method for heavy duty brick except in certain cases where some variations were used.

1. The brick were held under load at 1350°C for 10 hours instead of one and one-half hours.

2. Brick previously preheated at 1400°C for five hours were held under load at 1350°C for one and one-half hours.

3. Brick previously preheated at 1400°C for five hours were held under load at 1450°C for one and one-half hours.

¹ R. M. Howe and R. F. Ferguson, *Jour. Amer. Ceram. Soc.*, 3 [1], 32 (1921).

Additional Tests Made

Chemical Analysis.—In addition to the above tests, a sample of each brand was analyzed for Fe_2O_3 , Al_2O_3 and SiO_2 ; a series of absorption determinations were made, and a representative number of brands were examined petrographically.

Absorption.—For the absorption determinations, fifteen bricks of each brand were used. Five of these were tested as received, five after the constant volume test and the remaining five after the endurance test. The absorption was determined on irregular fragments broken from the brick and in accordance with the following formula:

$$A = \frac{W - D}{D} \cdot 100$$

A = per cent absorption,

W = weight of specimen after having been boiled in water for two hours and allowed to cool with the water,

D = weight of specimen after having been dried at 110°C .

Petrographic Examination.—The petrographic examinations were made by H. Insley. The purpose of this work was to approximate the

amount of free quartz present in the brick and to determine the successive effects of: (a) commercial burn; (b) burning at 1400°C for five hours; and (c) burning at 1450°C for seventy-two hours.

Dimensional Variations.—As a preliminary step ten specimens of fifteen different brands were measured and the mean variations from the standard $9 \times$

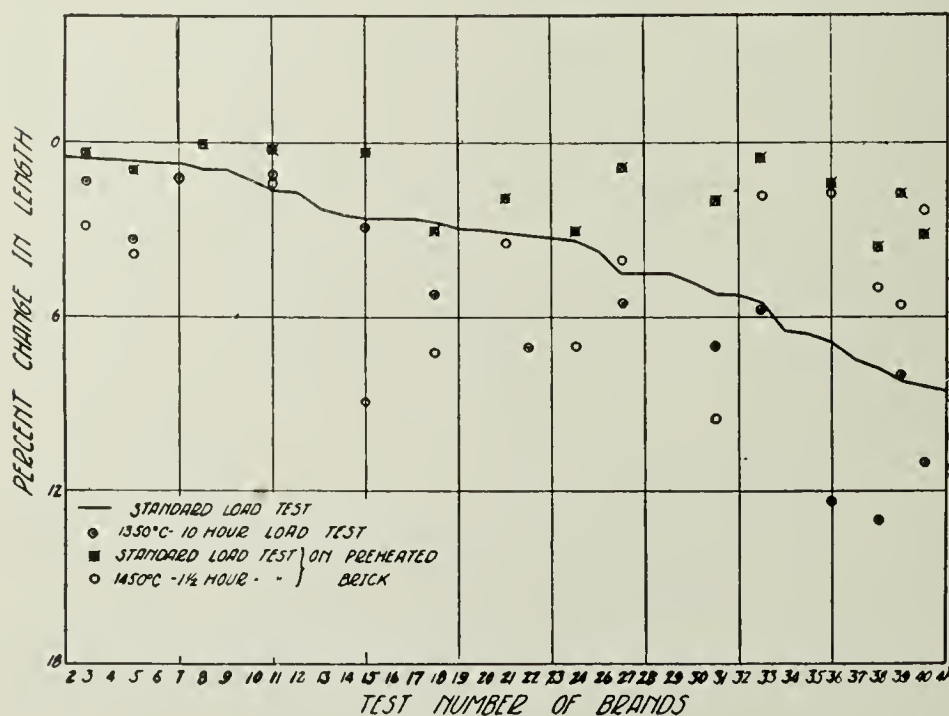


FIG. 1.

$4\frac{1}{2} \times 2\frac{1}{2}$ -inch dimensions calculated. It was found that the mean length of ten brands did not vary more than $\frac{1}{8}$ inch from 9 inches and the remaining five did not vary more than $\frac{3}{16}$ inch. One-eighth ($\frac{1}{8}$) inch is being used by some commercial concerns as the maximum allowable variation and this would seem to be a reasonable figure. The variations in thickness, on the whole, were within this specification but a much wider range of dimensions were encountered in the widths. It was found

that about 25% of the brick measured ran four and one-fourth inches or less in width. This would be equivalent to a variation of almost 6%.

Brands Numbered in Order of Resistance to Contraction in Load Test

It was determined to conduct the load test first, following the A.S.T.M. standard method for high duty brick. As shown in Fig. 1 the bricks were classified according to the results of this test, the brands showing the least linear contraction being placed at the left and following in order to those showing the most contraction at the right. The brands were then given test numbers according to this classification. These same designations were used in all of the tests. In this way the results of other tests were easily compared with the behavior of the brick in the standard load test.

RESULTS

Endurance Test

The endurance test is of particular interest in that it has been developed in the commercial field. This test is being used by a large commercial concern and is considered a very good measure of the probable behavior of refractories at furnace temperatures.

The results obtained in this work are shown in Fig. 2.

It is obvious that no relation exists between the reaction of brick to the standard load test and to the endurance tests.

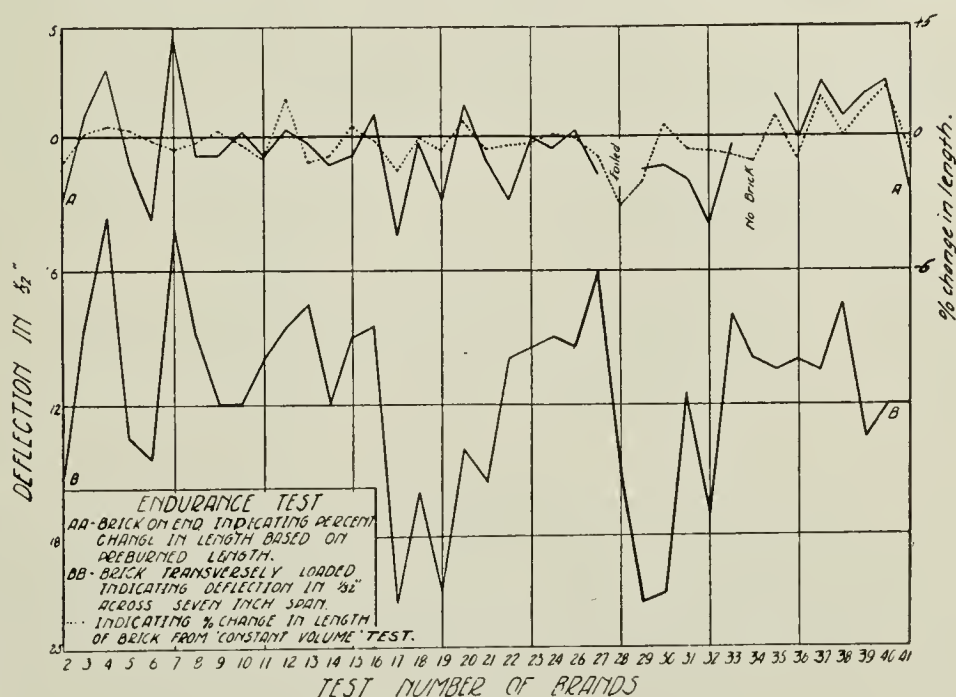


FIG. 2.

Brick simply placed on end in the endurance test show results agreeing in general with brick transversely loaded during the same heat treatment of 1450°C for 72 hours. Consider for example brands designated by numbers 2, 5, 6, 17, 18, 19 and 32. These brick show a large deflection under transverse load and also a comparatively large shrinkage when placed on end under no load other than their own weight. On the other hand, bricks showing the least deflection also show a comparatively low change in length, there being only two exceptions where this change in length is not well within a 2% limit.

The two bricks which prove to be the exceptions in this case are both

very high initially in free quartz and consequently retain a high viscosity to a point nearing their deformation temperature, thereby accounting for the low deflection under transverse load. The transformation of the quartz accounts for the exceptional change in length.

The results of the endurance test compare quite favorably with the results of quenching, fusion point and constant volume determinations and will be discussed in connection with these tests.

From the data at hand there is no relation evident of the effect of the method of manufacture on the properties of the brick in the endurance test. There is, however, a very interesting point brought out by the absorption data, the complete results of which are shown in Fig. 3. Since the change in absorption can be taken as a measure of the rate of vitrification, it can be said that the curves in question afford a rough picture of the rate at which the several brick are approaching vitrification. In Table I are two groups of brick with numbers indicating the respective changes in absorption for brick "as received" and after the endurance test. Similar information is shown graphically in Fig. 6.

TABLE I

BRICKS SHOWING LESS THAN $\frac{8}{32}$ DEFLECTION WHEN TRANSVERSELY LOADED IN THE ENDURANCE TEST

Test no.	Per cent absorption after endurance test	Change in per cent absorption
4	15.9	0.2
7	20.9	4.8
13	7.1	2.3
27	7.8	1.4
38	7.7	1.8
	<hr/>	<hr/>
Average	11.9	2.1

BRICKS SHOWING MORE THAN $\frac{15}{32}$ DEFLECTION WHEN TRANSVERSELY LOADED IN THE ENDURANCE TEST

Test no.	Per cent absorption after endurance test	Change in per cent absorption
2	10.1	7.4
17	4.4	9.0
18	10.8	....
19	4.8	10.1
21	5.2	4.2
28	3.0	14.3
29	2.0	8.6
30	5.2	5.0
32	8.7	4.1
	<hr/>	<hr/>
Average	6.0	7.8

This would seem to indicate that the transverse test is not so much a measure of the condition of the brick at the end of the test but rather an

indication of what the brick is doing at the temperature of the test. Disregarding brands 4 and 7 which, because of their high quartz content, act more like silica brick giving a high expansion with a resultant high absorption, it is evident that both the best and the poorest brick of the transverse test have no noteworthy differences in final absorption.

The changes in absorption show very interesting differences. The brick which deflected the least show an average change in absorption of 2.1% while the brands deflecting the most have an average change of 7.8%. In other words, a large deflection is indicative of low refractoriness since the brick are rapidly approaching vitrification and it would be reasonable to assume that such brick, under service conditions where they are held continuously at a high temperature, would in a comparatively short time become vitrified or at least reach a state of incipient vitrification. This would result either in deformation, if the brick is under load, or to spalling if they happen to be in a place where frequent and rapid changes in temperature take place.

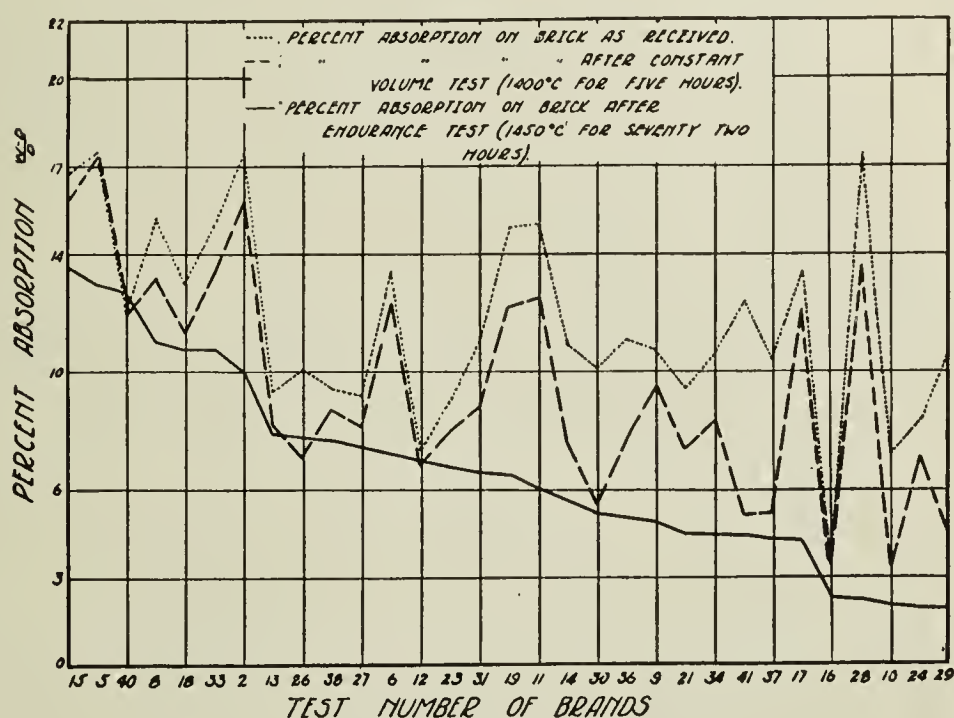


FIG. 3.

As shown in Table II the structure of the brick examined had changed materially during the heat treatment of the endurance test.

It may be said that one no longer has the same brick after this test. In every case where an examination was made the free quartz has been almost completely changed to cristobalite, while the clay matter was transformed into sillimanite and glass.

In the endurance test the following heat schedule was followed. The kiln was started in the afternoon and allowed to reach from 900° to 1000°C over night. The temperature was then carried up to 1350°C on a straight line schedule at the rate of 50° an hour. Up to this point, temperature measurements were taken by means of a platinum-platinum-rhodium couple (the point of the couple being as near as possible to the center of the area occupied by the specimens) and a recording Leeds and Northrup potentiometer. From 1350° to 1450° the temperature was raised at the rate of approximately 10° an hour and the temperature readings for this range, as well as during the balance of the test, were read by means of a

Leeds and Northrup optical pyrometer. The pyrometer was sighted on the end of a closed sillimanite tube of approximately one inch inside diameter. The end of the tube, and consequently the point at which measure-

TABLE II

RESULTS OF PETROGRAPHIC EXAMINATION OF BRICK

Number of brand	As received	After being held at 1400°C for 5 hours	After being held at 1450°C for 72 hours
3	About 50% quartz. Grog particles are quartz grains, somewhat shattered. Clay altered in part to sillimanite.	Slight alteration of quartz to cristobalite. Extensive development of sillimanite.	At least 40% cristobalite. 10% or less of unaltered quartz. Remainder sillimanite (well developed) with a little glass.
6	35% quartz. Quartz somewhat shattered but not inverted to cristobalite. Some development of sillimanite in clay matter.	Small inversion of quartz to cristobalite. Slightly more sillimanite than in commercial brick.	Stained black due to iron oxide. 20-35% cristobalite, 5% quartz. Remainder clay matter extensively altered to sillimanite.
7	About 75% quartz, some quartz grains slightly shattered but not inverted. No visible alteration of clay matter to sillimanite. Grog particles are quartz.	Some shattering of quartz. Slight formation of cristobalite. Development of sillimanite not prominent, but slightly greater than in commercial brick.	About 70% cristobalite, 5% quartz and remainder fairly well formed crystals of sillimanite with little glass.
13	About 10% quartz. No cristobalite. Small amount of sillimanite. Considerable glass and amorphous material.	About same in quartz and sillimanite content as untreated, but very different in appearance. Color darker and iron stains more pronounced.	
23	Less than 5% quartz. Considerable glass. Slight change of clay matter to sillimanite. No cristobalite.	Much glass. Clay matter largely transformed to sillimanite. Large sillimanite crystals present and many small ones.	
27	Less than 5% quartz. No cristobalite. Considerable glass. Largely amorphous material. Little crystalline sillimanite.	About same amount of quartz. No cristobalite. Considerable glass. Moderate quantity of small crystals of sillimanite.	
38		10-15% quartz. No cristobalite noted. Moderate amount of glass. Well developed small crystals of sillimanite abundant.	

- | | | | |
|----|---|---|--|
| 39 | About 10% or less quartz. No inversion to cristobalite, but clay matter is extensively changed to crystals of sillimanite. Grog particles unusually coarse. Quartz mostly in bond clay. | Very similar to "commercial" both in mineral composition and development of sillimanite. Very small amount of cristobalite present. | Quartz inverted to cristobalite. Fairly large crystals of sillimanite. All of clay changed to sillimanite and glass. |
| 41 | 20-25% quartz. No cristobalite. Considerable alteration of clay to sillimanite. Sillimanite in fine intermeshed crystals. Grog particles contain more quartz than do bond. | Large part of quartz inverted to cristobalite. Remnants of quartz grains surrounded by rims of cristobalite. Clay extensively altered to sillimanite. Sillimanite crystals well-formed and large. | Quartz entirely inverted to cristobalite. Sillimanite development very extensive. |
| 42 | About 10% quartz. Apparently not shattered. No cristobalite. Considerable sillimanite development. | Bond clay an olive yellow, grog particles white. Except in color differs little from commercial brick. A small amount of cristobalite. Little, if any, more sillimanite than in commercial brick. | Quartz almost completely changed to cristobalite. Sillimanite development very extensive. |

ments were taken, was as near as possible at the center of the area occupied by the specimens. As an indication of temperature uniformity in the kiln, cones were also placed on the bag walls and at the four corners and center of the kiln proper.

The Constant Volume Test

This test was made to determine the relation between the change in volume of a brick, when reheated, and its value as a refractory. The bricks were carefully measured before and after the test for average length, and the difference taken as a rough measure of the volume change. The determination of actual volume change would have involved much more work and, because of the nature of the material, would very probably have yielded data of no greater value than that afforded by the measurement of linear change.

The results obtained are shown by the dotted curve in Fig. 2. From a study of these data, and comparing with results from other tests, there is no evident relation since in nearly all cases, the change is not big enough to be of value for comparative purposes.

The curve (Fig. 2) can be compared with the linear change in the en-

duration test. From the two curves it is evident that heating to 1450°C has produced results more pronounced and, as already stated, fairly comparable with other tests.

The absorption data on the specimens from the constant volume test have proved to be of considerable interest and probable value. The results are plotted in Fig. 7 and will be discussed later in connection with the quenching test.

Platinum platinum-rhodium thermocouples were used throughout for the measurement of temperatures in the constant volume test and cones

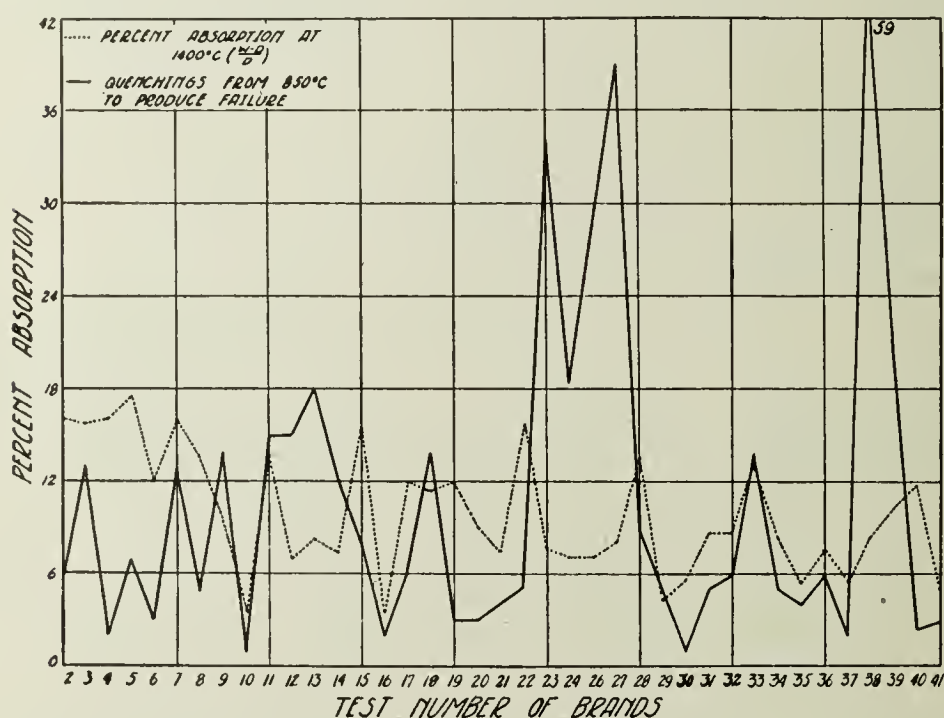


FIG. 4.

the test was completed at midnight following the day on which the kiln was set. As measured by cones this heat treatment was equivalent to the softening point of Seger pyrometric cone 15.

The Quenching Test

The brick for the quenching test were first reheated at 1400°C for five hours. They were allowed to cool slowly with the kiln and were weighed to the nearest ounce. Fifteen bricks of each brand were prepared in this way, five being used for the quenching work from each temperature; that is, from 850° , 1100° and 1350°C . The quenching treatment was continued until the end of the brick had completely spalled away, and each brick was then weighed and the per cent loss in weight calculated.

In nearly all cases the first spall carried away the entire end of the brick but occasionally only a corner was lost requiring one or two more quenchings before the brick was considered to have failed. The complete results of quenchings from the three temperatures are given in Fig. 5.

The two main results to be considered in this test are the weight loss and the number of quenchings required to produce failure.

were used, similar to the method described for the endurance test, to indicate the uniformity of temperature in the kiln. The kiln was allowed to reach red heat over night and was then carried up to 1400° on a straight line schedule at a rate sufficiently high to reach the maximum temperature at seven o'clock in the evening. In this way

A study of the data on loss in weight of the several brands has not resulted in the establishment of any relation between the laboratory results and the nature of the brick or their reactions to other tests. The temperature from which the quenchings were made also had very little general effect on the weight loss.

The second factor, that is, the number of quenchings to produce failure, has, however, brought out points of interest. A study of the curves in Fig. 5 shows that, while quenching from 1350°C will undoubtedly pick out brick of low resistance to temperature change, it does not show sufficient

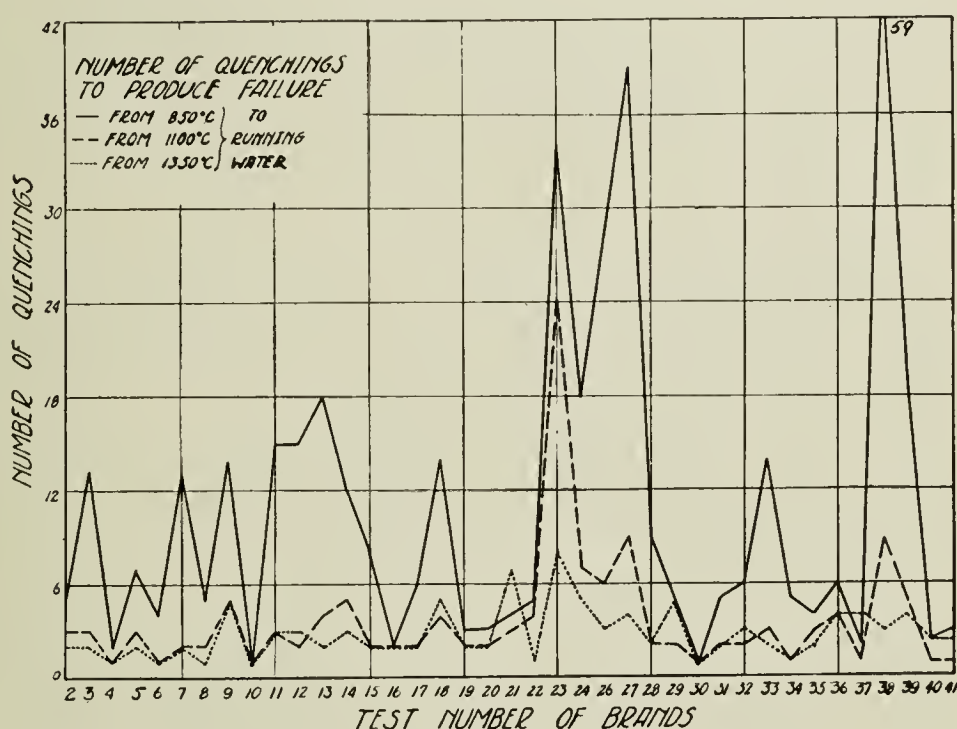


FIG. 5.

difference between the best and the poorest to enable one to make comparisons. Quenching from 1100°C has not increased the value of the test very much, if at all. Brands 23, 27 and 28 withstood this test appreciably better but in most cases the number of quenchings were either the same or differed by not more than one quenching. In fact, some brick, as the curves will show, appeared better in the 1350° test. From this it would appear that if quenching from 1100°C has any advantage over that from 1350° the gain lies within the limits of error of the test.

It is evident that the quenching from 850° has produced a decided change. Although some brands still failed, on an average, in the first quenching there is a much wider range between the best and poorest brands. The data show a ratio of maximum to minimum number of quenchings equal to 59 to 1, as compared with a ratio of 8 to 1 for the 1350°C quenchings. The general average for all brands was 6.7 quenchings for the 850° test as against 2 for the 1350° test.

In general, brick of high free quartz content or high plastic clay (and consequent high flux) content show the least resistance to sudden temperature change. This point is brought out clearly by a correlation of chemical analyses and quenching results. It will be further discussed in connection with the former test.

Kiln temperatures were measured by means of a platinum-platinum-rhodium thermocouple placed in the kiln approximately six inches from

the inner face of the door, and just to one side of and midway from top and bottom of the auxiliary panel in which the test brick were heated. A counterweighted door was used for the purpose of closing the panel while the test brick were being quenched. In this way the heat was retained in the kiln so that not more than ten minutes were required to reach the desired temperature after the specimens were replaced in the kiln door.

The Load Test

The results of this study are shown in Fig. 1. It was not expected that the work would result in new data on behavior of refractories under load at high temperatures but was conducted mainly for the purpose of determining the relation of the load test to the other tests under investigation.

This report does not permit a full discussion of the data, but the following points seem to be the most important developments:

1. The load test does not produce results which are comparable with any other test of this investigation.

2. The load test, as has been shown by other investigators,¹ is an excellent method for classifying so-called No. 1 from No. 2 quality re-

fractories but does not serve as a means for grading various refractories in any one class.

3. As regards aluminous brick, the load test can be considered as a measure of the heat treatment received by the specimen in the commercial kiln. This has been noted by Bleininger in his work on aluminous refractories² and is very well demonstrated by the

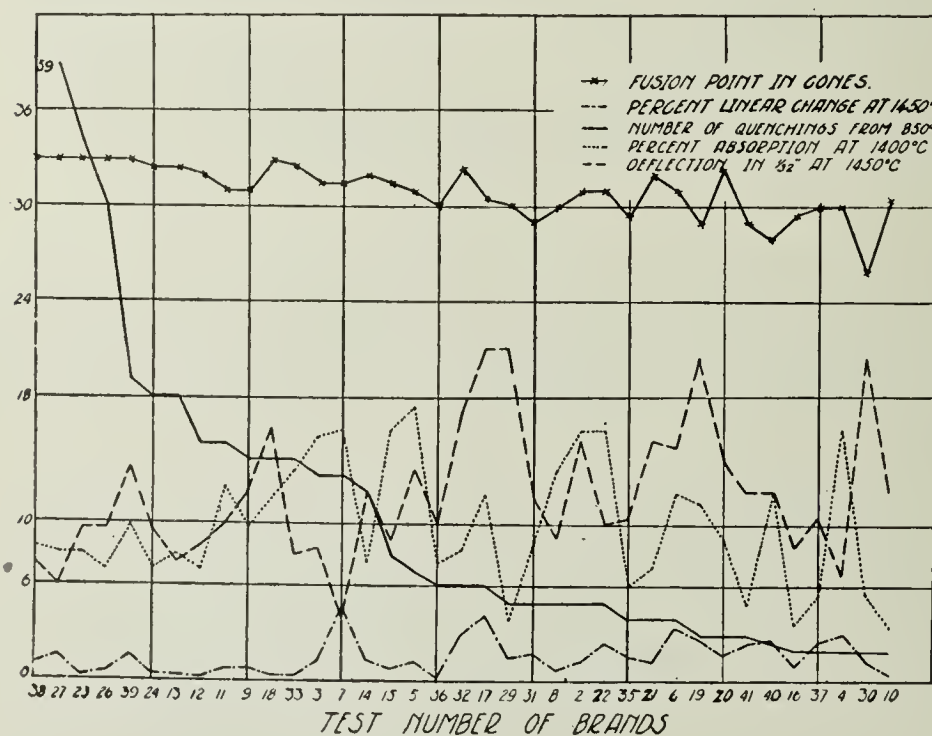


FIG. 6.

load test behavior of brick shown to the right in the curves of Fig. 1. These specimens as received give very poor load test results but when tested after having been preheated to 1400° for five hours their resistance to deformation compares favorably with the brick of siliceous

¹ Bur. Standards, *Tech. Paper 7*; *ibid.*, 159.

² A. V. Bleininger, "Note on the Load Behavior of Aluminous Refractories," *Jour. Amer. Ceram. Soc.*, 3 [2], 155 (1920).

type which, because of their natural rigidity at 1350°C, are but slightly affected in the load. The results on these are therefore grouped to the left of the diagram (Fig. 1). The load test as now used will put many brands of aluminous brick of accepted commercial value, in a class with low grade refractories unless the fusion point is also considered. There is a possibility that the load test, if conducted on preheated brick, might be considerably improved as a test for classifying No. 1 quality refractories.

Fusion Point

Resistance to fusion of the refractories is measured by comparing with Seger pyrometric cones. With the exception of three brands, the results are shown graphically in Fig. 6. The omitted brands failed consistently in the tests to which they were submitted and were considered as of too inferior quality to be classed with high heat duty refractories. The results are discussed in connection with the other tests of this investigation.

A composite diagram of the tests so far described is shown in Fig. 6. The brands are graded according to the number of quenchings received from 850°C to running water. This method of classifying would designate brands 9, 11, 12, 13, 23, 24, 26, 27, 38 and 39 as the best ten of those included in the investigation. In this connection the following points have been noted.

1. In the group of ten best brands the fusion point is equal to, or higher than, cone 32 and lower than cone 32 for the balance.
2. The absorption after reheating at 1400° for five hours lies between 6 and 10% for the best refractories and above or below this range for the balance.
3. The deflection in the transverse endurance test does not exceed $10/32$ inch for the best refractories.
4. The per cent linear change after reheating at 1450° for seventy-two hours does not exceed one per cent for the best grades; *i. e.*, brick which can withstand, without failure, fifteen or more quenchings from 850°C to running water.

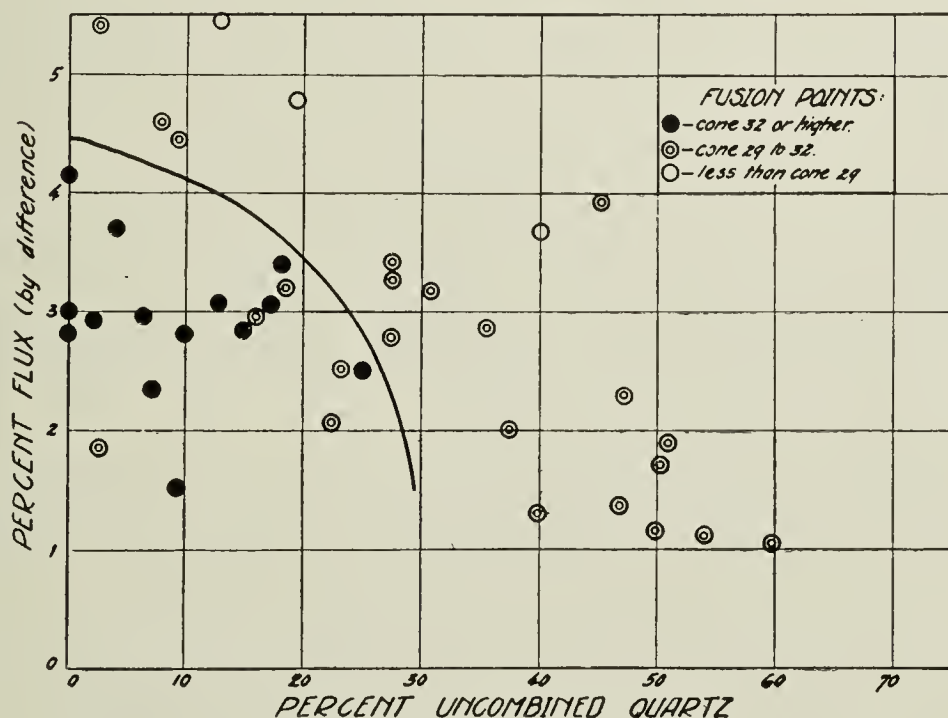


FIG. 7.

There are of course exceptions to each of the above rules but these relations appear, on the whole, to be very good.

Chemical Analysis

The chemical analysis comprised determination of SiO_2 , Al_2O_3 and Fe_2O_3 the balance being considered as flux. The method followed was essentially the A.S.T.M. standard with the exception that, in the Fe_2O_3 determination, the correction for silica was not made. If plotted on a triaxial diagram, the combined results would lie in the following field:

	Per cent
Al_2O_3	15-50
SiO_2	45-85
Total flux.....	0-10

If calculated to clay, uncombined SiO_2 and flux the results would lie in the field:

	Per cent
Clay.....	40-98
Uncombined SiO_2	0-60
Flux.....	0-10

Several methods of plotting, to show the relation of chemical analyses to other physical properties, suggest themselves but that shown in Figs. 7 and 8 was finally adopted.

That a close relation exists between chemical composition and fusion point (Fig. 7) has been shown by other writers and is naturally to be expected.

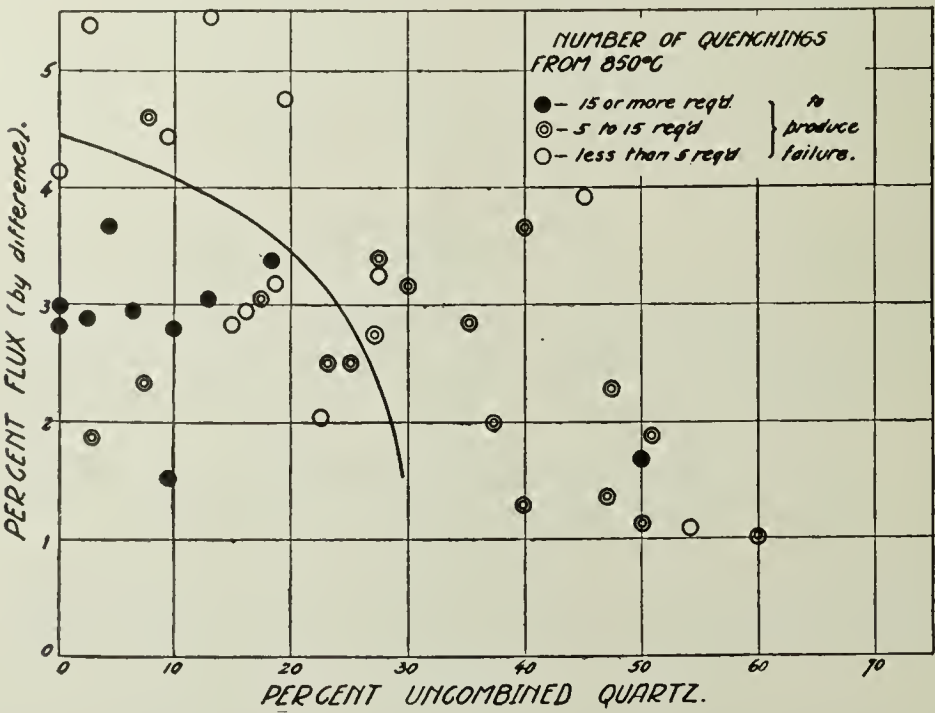


FIG. 8.

It was not so evident, however, that resistance to quenching was as dependent on chemical composition as the data in Fig. 8 would seem to indicate. In fact, if the data at hand are correct any refractory having a fusion point lower than cone 32, or which contains more than twenty per cent uncombined SiO_2 and 4% total flux, cannot be expected to satisfactorily resist spalling.

Conclusions

This report cannot be complete until the laboratory results have been correlated with the service tests. Because the results brought out by the

tests here reported merit consideration they are presented for discussion. They are again briefly stated as follows:

1. The endurance test, while furnishing results of undoubted interest and value, is difficult and expensive and offers no better means of testing refractories than other and simpler methods.

2. The constant volume test, used as a preliminary step to quenching, offers a means for obtaining valuable absorption data.

3. The quenching test, using 850°C as the furnace temperature, is an excellent means for judging comparative resistance to thermal shock. While there is an obvious relation between resistance to sudden temperature change, fusion point and chemical analysis, it does not seem sufficiently close to warrant the complete replacement of the quenching test by either or both of the latter tests.

4. Refractoriness is a property of primary importance. The user of refractories is of course not directly interested in the fusion point of the refractory he uses for it is not as a rule subjected in use to heat treatments that would materially soften them. Nevertheless, because of its relative simplicity of determination and the close relation of the results obtained to those of other tests (such as chemical analysis, resistance to quenching, volume change), the fusion determination continues to be desirable as a test.

5. Evidence indicates that for classifying "high heat" and "medium heat-duty" refractories the load test could be improved by preheating the specimens.

The "fusion point" determination serves the same purpose as the load test and is more easily accomplished.

The load test does justify itself as a means for determining whether or not an aluminous refractory is sufficiently well burned to resist considerable load when that load is applied during the initial heating to extreme temperature.

Since load carrying ability is not an important factor in boiler settings it is questionable whether the load test should be specified.

6. Chemical analyses are a source of very interesting and important information, and as such are worthy of consideration. From the evidence at hand it is seen that the chemical analysis will serve as an indirect measure of the "fusion point." Since the free quartz content can be easily and quickly approximated petrographically it is questionable which is the more valuable, chemical analysis or fusion point and petrographic examination.

Briefly, the data at hand tends to show that a combination of two or more of the following tests can serve as suitability and control test for stoker fired boiler refractories: quenching (with preheating), fusion point determination, chemical analysis, petrographic examination.

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ORIGINAL PAPERS

FURTHER STUDIES OF PORCELAIN GLAZES MATURING AT HIGH TEMPERATURES¹

BY ROBERT TWELLS, JR.²

ABSTRACT

The investigation covers three fields of glazes: Series A contains 21 glazes with

variations in composition as shown in the formula

0.3 K ₂ O	}	1.3 Al ₂ O ₃ (11.0SiO ₂).
0.2 to 0.7 CaO		
0.0 to 0.5 BaO		
0.0 to 0.5 MgO		

Series B contains 10 glazes, each having the formula

0.3 K ₂ O	}	1.3 Al ₂ O ₃ (11.0SiO ₂),
0.7 CaO		

but having their clay content varying triaxially between Florida kaolin, North Carolina kaolin, and Kentucky ball clay No. 4. Series C contains 20 glazes with variations in composition as shown in the formula

0.2 K ₂ O	}	0.8 to 1.6 Al ₂ O ₃ (8.0 to 14.0 SiO ₂).
0.8 CaO		

The method of experimentation consists of grinding the corner glazes of each series wet, for 18 hours, cross blending the corner glazes to produce the intermediate glazes, applying the glazes by dipping to green porcelain discs, and firing them in commercial periodic and tunnel kilns to temperatures between cone 16¹/₂ and cone 19 flat. The glazes were examined with the naked eye and a 10 X pocket lens.

The triaxial replacement of CaO by MgO and BaO, as tested, makes practically no change in the appearance of the glazes. With the pocket lens the bubbles in the glazes appear smaller and more numerous, near the BaO apex.

¹ A contribution from the Research Laboratories of the Champion Porcelain and Jeffery-Dewitt Insulator Companies, Detroit, Michigan. See Robt. Twells, Jr., "The Field of Porcelain Glazes Maturing between Cones 17 and 20," *Jour. Amer. Ceram. Soc.*, 5 [7], 430 (1922).

² Presented before the Whiteware Division, Pittsburgh Meeting, February, 1923.

When fired in the periodic kilns for 42 hours the transparency of all the glazes increases with the temperature. The glazes fired in the tunnel kiln to cone 19 flat in 31 hours are more opaque and smoother than in the periodic kiln at three cones lower temperature.

The triaxial replacement of the Florida kaolin, by North Carolina kaolin and Kentucky ball clay No. 4 produces relatively little change in the fired appearance. The glazes containing all ball clay or a mixture of ball clay and North Carolina kaolin overfire at a lower temperature than do those containing all kaolin or a mixture of Florida kaolin and ball clay.

The best glazes with 0.2 K_2O and 0.8 CaO have approximately an alumina:silica ratio of 1:9 and 1:11 for the field covered. These glazes are generally more transparent than the glazes with 0.3 K_2O ; otherwise the results are similar.

The conclusions are: (1) that the nature of the firing conditions are of the utmost importance in the development of a glaze, and (2) that an intelligent choice between glazes of equally desirable appearance requires a resort to petrographic method and mechanical tests.

Introduction

Some time ago Sortwell¹ published the results of an investigation of porcelain glazes maturing between cones 10 and 16. A short time later the writer submitted a paper to the SOCIETY entitled, "The Field of Porcelain Glazes Maturing between Cones 17 and 20."²

These two investigations were studies of the effects of varying the molecular equivalents of alumina and silica while holding the RO members constant at 0.3 equivalent of K_2O and 0.7 equivalent of CaO .

From time to time these laboratories have had occasion to refer to both articles in order to write out at once the formula of a glaze for use at a particular temperature. When used in this way the diagrams have proved to be reliable even though in some cases the raw materials and the firing conditions were not exactly the same as in the original experiments.

The scarcity of published information regarding high temperature glazes has made it necessary to continue the work on this subject in an attempt to cover the whole field as completely as possible.

Methods of Experimentation

The work reported in this article consists of a study of three glaze series. The field covered by each series will be shown later in some detail. The methods used for making each series were the same. In each case the corner glazes only were weighed out and ground wet for 18 hours in small ball mills. The intermediate glazes were produced by cross blending the liquid corner glazes in the proper proportions as calculated from their relative specific gravities and molecular weights. Care was taken in all

¹ H. H. Sortwell, "High Fire Porcelain Glazes," *Jour. Amer. Ceram. Soc.*, 4 [9], 718 (1921).

² *Loc. cit.*

cases to obtain a thorough mixing of the component glazes. The body used had the same composition as in the previous experiment.

English ball clay (M. and M.)	5.0%
North Carolina kaolin	12.0
Florida kaolin	8.0
English china clay (M. W. M. No. 2)	30.0
Flint	30.0
Feldspar	15.0
	<hr/>
	100.0%

The test pieces were made by extruding a column of the body one inch in diameter from a small hydraulic plunger press¹ and cutting it into $\frac{3}{8}$ -inch lengths.

These discs were dried first in air; then in a laboratory steam drier, but were moistened with water just before being dipped into the glaze. The glazes were applied to the body in a much heavier coat than would ordinarily be used. The purpose of this was to magnify any defects of the glaze.

In each sagger was placed a cone pat containing three cones of the proper number. Around this was arranged a set of the discs, each coated with one of the glazes which went to make up a series. Some of the saggars were fired in different parts of downdraft periodic kilns. These kilns reached their maximum temperature in approximately forty-two hours. Some of the saggars were fired in a Dressler Tunnel Kiln,² when the cars were being put into the kiln once every hour. In this case the maximum temperature was reached in about thirty-one hours. One sagger was fired in the Dressler kiln when the cars were being put in an hour and one-half apart. In this case the maximum temperature was reached in approximately forty-six hours.

RAW MATERIALS USED

Feldspar—Maine Feldspar Co., Auburn, Maine.

Whiting—Solvay Process Co., Delray, Mich.

Flint—Pennsylvania Pulverizing Co., Hancock, W. Va.

Barium Carbonate—Mallinckrodt Chemical Works, St. Louis, Mo.

Talc—No. 1 White Brand—G. H. Gillespie Co., Madoc, Ontario, Canada.

Kentucky Ball Clay No. 4—Kentucky Construction and Improvement Co., Mayfield, Ky.

Florida Kaolin—Edgar Plastic Kaolin Co., Edgar, Fla.

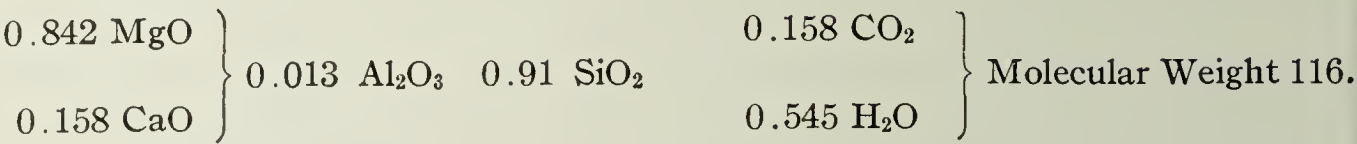
North Carolina Kaolin—Harris Clay Mining Co., Spruce Pine, N. C.

With the exception of the talc all of the raw materials were assumed to have the same composition as the theoretically pure substances. From

¹ "Tentative Methods of Testing Electrical Porcelain," *Jour. Amer. Ceram. Soc.*, 5 [4], 83, Pt. II, *Year Book* (1922).

² "Preliminary Rept. of Comm. on Fuel Conservation on Railroad Tunnel Kiln," *Jour. Amer. Ceram. Soc.*, 5 [9], 609 (1922).

the average of four analyses the molecular composition of the talc was calculated to be:



This formula was used as a basis when talc was introduced into Series A. The assumption that the other materials are pure caused errors which are negligible except in the case of the feldspar.

In series A and C a considerable error was introduced by the assumption that the feldspar used was a pure potash feldspar. The actual chemical analysis of the feldspar is approximately as shown below.

SiO ₂	72.73%		
Al ₂ O ₃	16.66		Molecular Composition
Fe ₂ O ₃	0.12		
TiO ₂	————	0.49 K ₂ O	} 1.0 Al ₂ O ₃ 7.39 SiO ₂ 0.15 H ₂ O
CaO	Trace	0.25 Na ₂ O	
MgO	0.28	0.04 MgO	
K ₂ O	7.69		
Na ₂ O	2.54		Molecular Weight 612
Loss on Ignition	0.45		
	————		
	100.47%		

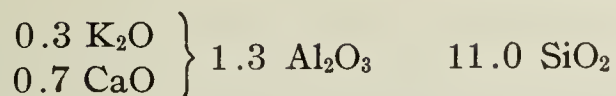
If one should wish to duplicate any of the glazes in these two series from the diagrams, it would be necessary to use a feldspar of approximately the same composition as given above, and to introduce it as though it were a pure potash feldspar. For practical purposes the results would then be similar to these. From a theoretical standpoint the error affects the interpretation of the results relatively little. This is because the error is chiefly in the RO group, and is practically the same for each glaze in the series. The extent of the variation of the actual composition of the corner glazes from their theoretical compositions will be shown later.

Methods of Examining the Fired Glazes and Reporting the Results

After each series had been fired in several different ways, the glazed test pieces were sorted out into their respective positions. Each set of glazes was inspected twice: first with the naked eye, and second with a Bausch and Lomb 10 X Triple Aplanat magnifying glass. The results of these examinations are described for each set of glazes. Whenever practical, the results are also shown by means of diagrams:

Series A

The purpose of this series was to study the effect of replacing CaO by MgO and BaO in one of the best glazes from the previous work. The glaze:

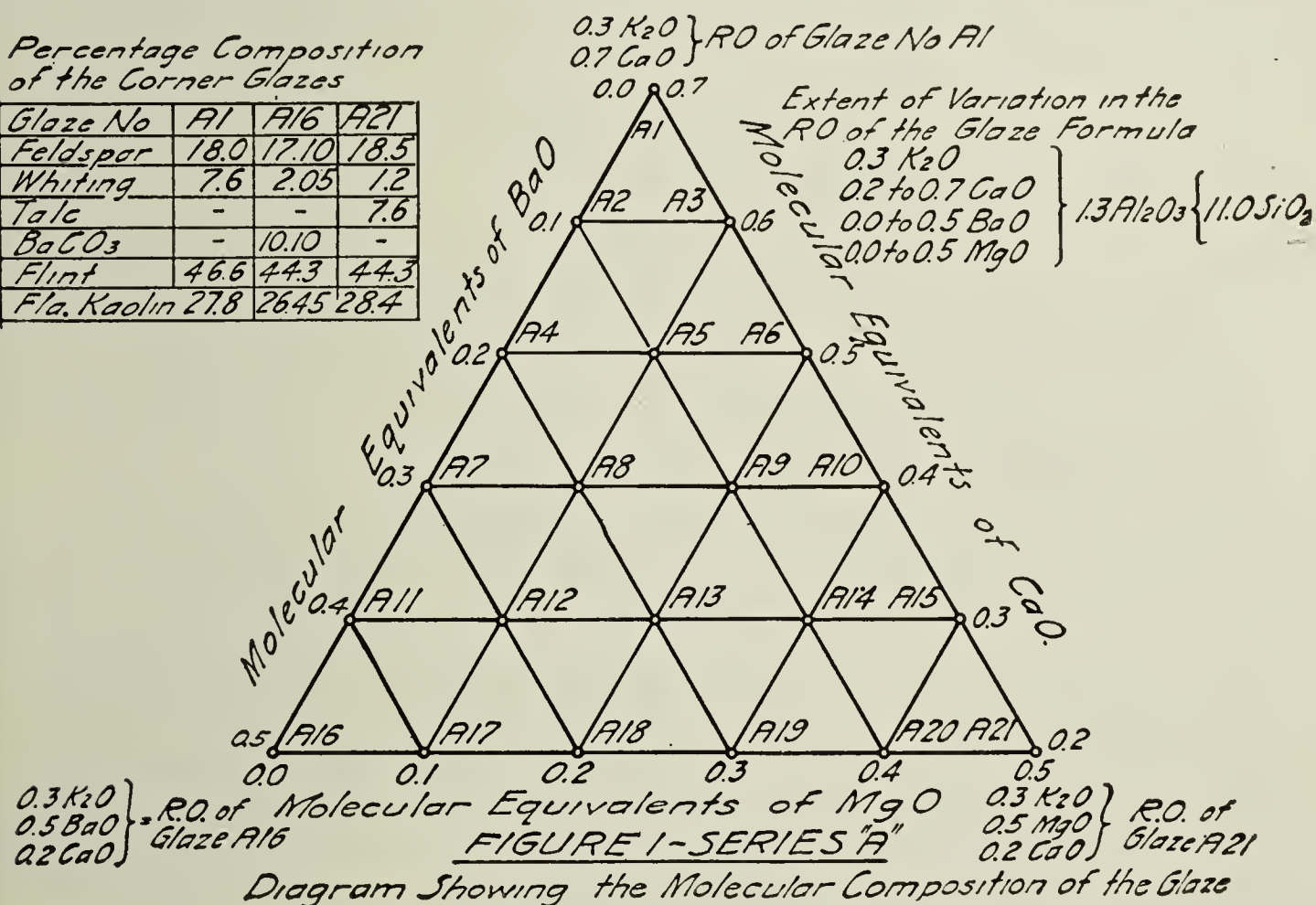


was chosen for a basis for this experiment because it seems centrally located in the area of good glazes at these temperatures. The field covered may be seen by reference to Fig. 1.¹

The number of molecular equivalents of K_2O , Al_2O_3 and SiO_2 was held constant; the CaO was varied between 0.2 and 0.7 equivalents, being

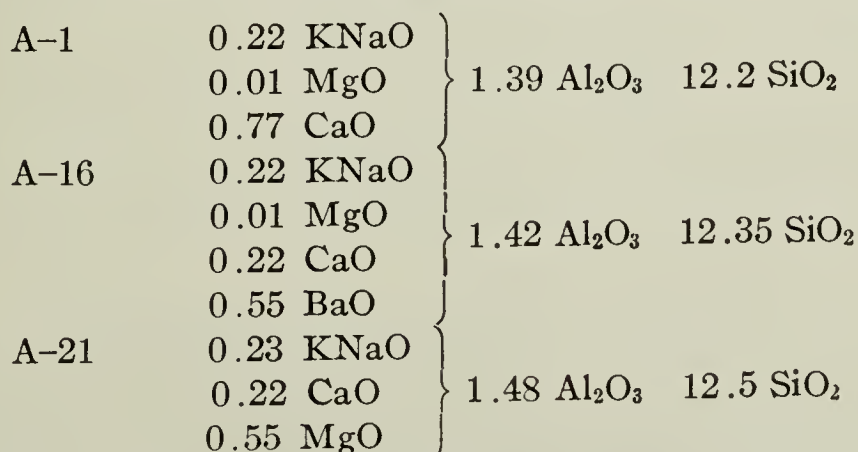
Percentage Composition
of the Corner Glazes

Glaze No	A1	A16	A21
Feldspar	18.0	17.10	18.5
Whiting	7.6	2.05	1.2
Talc	-	-	7.6
BaCO_3	-	10.10	-
Flint	46.6	44.3	44.3
Fla. Kaolin	27.8	26.45	28.4



replaced triaxially by BaO and MgO . The MgO was derived from talc which has some advantages over its other possible sources.²

¹ The molecular compositions given in Fig. 1 are theoretically based on the introduction of the feldspar as a pure potash feldspar instead of according to its chemical composition. Based upon the latter, the actual molecular formulae of the three corner glazes in Series A are calculated to be as shown below:



² Robt. Twells, Jr., "Talc as a Flux for High Tension Insulator Porcelains," *Jour. Amer. Ceram. Soc.*, 5 [10], 678 (1922).

Appearance of the Fired Glazes

Cone 16¹/₂, Periodic Kiln, 42-Hour Burn.—(1) Naked Eye: The glazes are all similar. They are smooth and semi-opaque. On the whole their appearance is pleasing. Glazes A-1, A-3, A-4, A-8, A-12 and A-15 contain one or more open bubbles at the surface which would tend to catch dirt.

(2) Magnifying Glass: On the CaO and MgO side of the triangle the glazes contain a net-work of large bubbles interspersed with smaller ones. At and near the BaO apex the glazes contain numerous small bubbles with an occasional larger one.

Cone 16³/₄, Cone 17 Just Started, Periodic Kiln, 42-Hour Burn.—(1) Naked Eye: All of the glazes have a smooth appearance. Practically no difference can be detected between them. They are more nearly transparent than at cone 16¹/₂, but still are partly opaque. At the surface of glazes A-1, A-13, A-16, A-18 and A-21 there are one or more open bubbles.

(2) Magnifying Glass: The glazes contain a net-work of medium-sized bubbles with an occasional larger one. The bubbles in A-16 appear small but more numerous than in the others.

Cone 17 Down, 18, Just Tipped, Periodic Kiln, 42-Hour Burn.—(1) Naked Eye: The glazes are all bright and transparent, with the exception of A-16, which seems to be somewhat cloudy. Close observation discloses minute bubbles in all of the glazes which are visible to the naked eye. Glazes A-7, A-11, A-12 and A-21 have open bubbles at the surface.

(2) Magnifying Glass: The glazes all contain a net-work of medium-sized bubbles, with an occasional larger bubble, with the exception of A-16. It contains a great many fine bubbles with an occasional large bubble.

Cone 18 Down, 19¹/₄, Periodic Kiln, 42-Hour Burn.—(1) Naked Eye: The glazes are all bright and very transparent. A few small bubbles are visible on close observation. Glazes A-3, A-6, A-7, A-11, A-13, A-17 and A-21 contain one or more open bubbles at the surface.

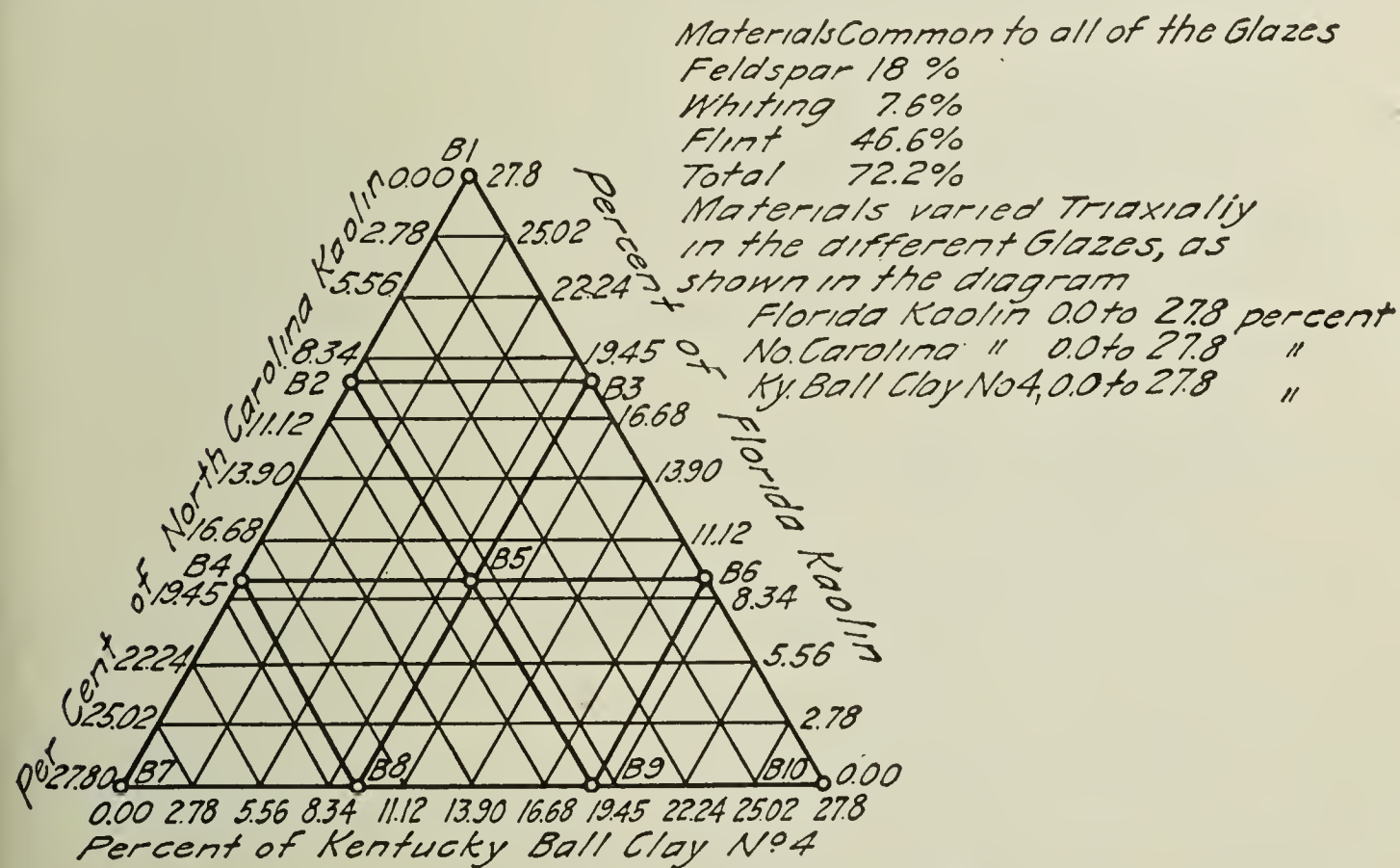
(2) Magnifying Glass: A-16 contains very fine bubbles and a few big ones. The rest contain medium-sized bubbles with an occasional larger one.

Cone 19 Flat, Dressler Kiln, 31-Hour Burn.—(1) Naked Eye: All of the glazes are very smooth, very white, and almost opaque. There are no open bubbles visible at the surface.

(2) Magnifying Glass: All of the glazes contain many minute bubbles with an occasional larger one.

Conclusions.—Within the limits of this experiment the triaxial replacement of CaO by BaO and MgO does not produce a noticeable change in the appearance of the fired glazes. Under the magnifying glass, the glazes near the BaO apex contain somewhat smaller bubbles than those at either the CaO or MgO apexes. When fired under similar conditions

in the periodic kilns the transparency of the glazes tends to increase with the temperature. This is also true of the number of bubbles in the glazes visible to the naked eye. On the contrary the number of open bubbles at the surface of the glazes does not seem to depend upon either the composition of the glaze or the temperature of the firing. They seem to occur at random. It is interesting to note the improved appearance of the glazes fired in the Dressler kiln with the short firing period. At cone 19 flat these glazes are more opaque than those from the periodic kiln at cone $16\frac{1}{2}$. The absence of the open bubbles at the surface of the glazes when fired in this way is also encouraging.



Series B

The purpose of this series was to determine the effects on the fired appearance of a glaze due to replacing Florida kaolin triaxially with Kentucky ball clay and North Carolina kaolin. Glaze A-1, from the previous series, was used as a basis for this experiment. The method of laying out the series and the composition of the glazes may be seen by reference to Fig. 2.

Appearance of the Fired Glazes

Cone 16 Down, 17 Just Started, Periodic Kiln, 42-Hour Burn.—(1)
 Naked Eye: All of the glazes appear smooth and semi-opaque, except B-9, which seems rough.

(2) Magnifying Glass: The glazes all contain many small bubbles and a few large ones. Glaze B-9 has a lot of open bubbles at the surface.

General Formula $\left. \begin{matrix} 0.2 K_2O \\ 0.8 CaO \end{matrix} \right\} x Al_2O_3 \{ y SiO_2$

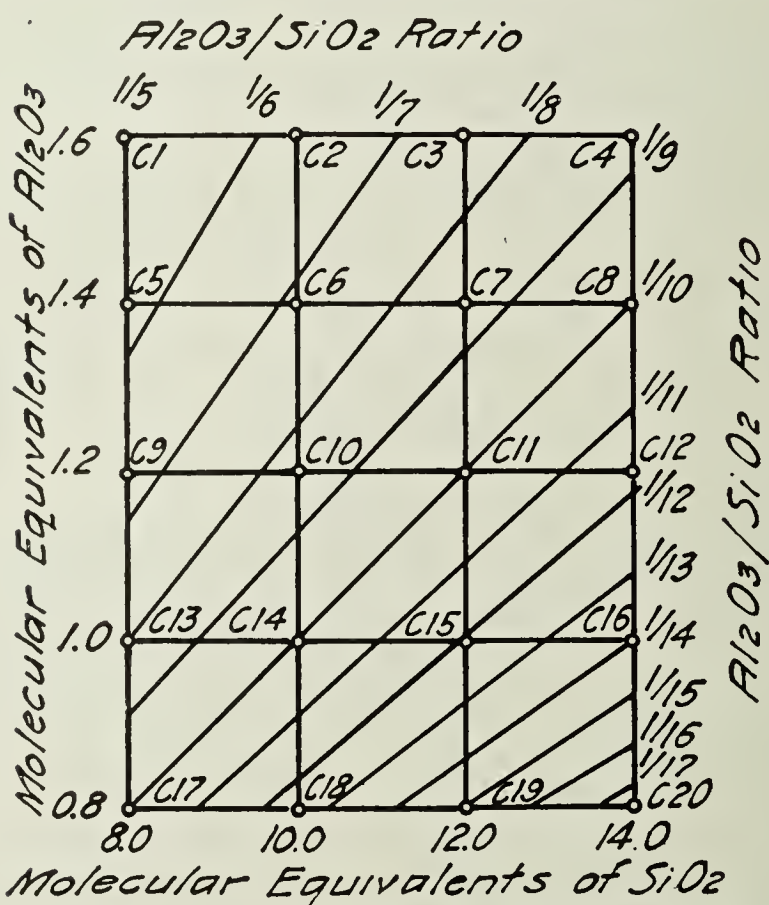
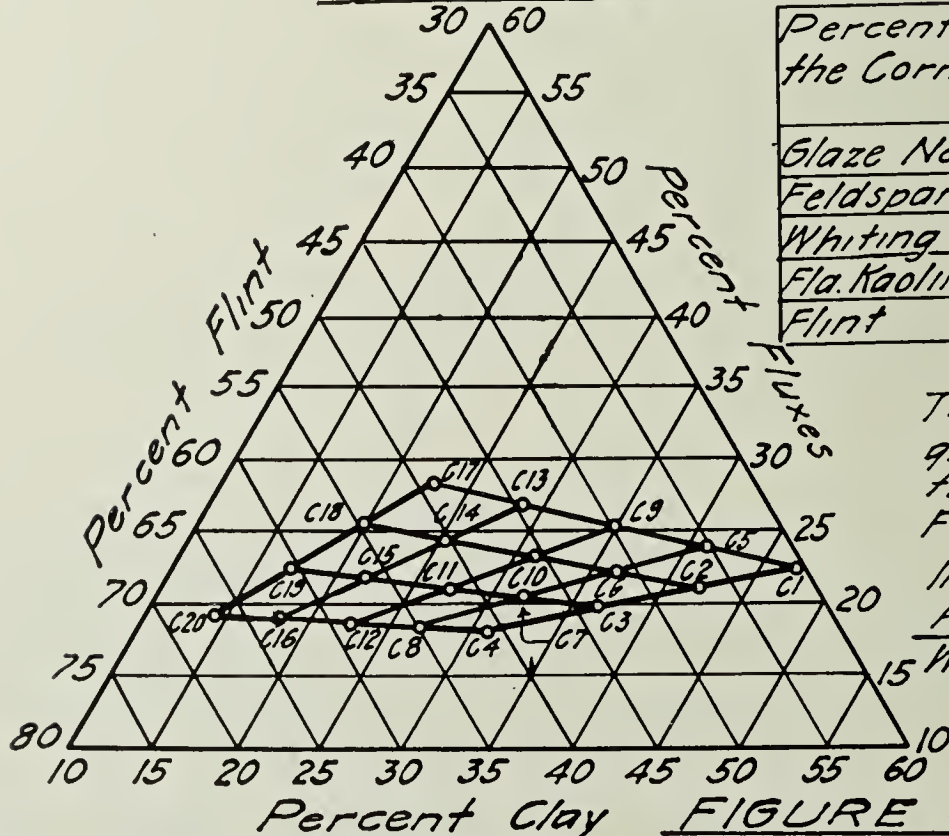


Diagram showing the Molecular Composition of the Glazes

FIGURE 3 SERIES C



Percentage Composition of the Corner Glazes				
Glaze No	C1	C4	C17	C20
Feldspar	14.1	9.65	16.3	10.65
Whiting	10.1	6.95	11.7	7.70
Fla. Kaolin	45.5	31.30	22.7	14.85
Flint	30.3	52.10	49.3	66.80

100.0 100.0 100.0 100.0
The percent of fluxes given is the sum of the whiting & the Feldspar

In each case the ratio $\frac{\text{Feldspar}}{\text{Whiting}} = 1.39$

Diagram Showing the Percent Composition of the Glazes
FIGURE 4 SERIES C

Cone 17 Down, 18 Tipped, Periodic Kiln, 42-Hour Burn.—(1) Naked Eye: The glazes are similar in appearance. All are smooth glazes, slightly more transparent than at cone 16 down.

(2) Magnifying Glass: The glazes all contain small bubbles interspersed with larger bubbles.

Cone 18 Down, $19\frac{1}{4}$, Periodic Kiln, 42-Hour Burn.—(1) Naked Eye: All of the glazes have a smooth appearance except B-8 and B-9, which contain a few open bubbles at the surface. The glazes are slightly more transparent than at cone 17 down, but are still somewhat opaque. B-8, B-9 and B-10 are noticeably more transparent than the others. This is particularly true of B-9.

(2) Magnifying Glass: All of the glazes except B-9 and B-10 contain a lot of medium-sized bubbles and a few larger ones. The bubbles in B-9 are mostly large ones, but are not as numerous. B-10 contains a lot of bubbles, some of which are very large.

Cone 19 Flat, Dressler Kiln, 31-Hour Burn.—(1) Naked Eye: All of the glazes are smooth, white and semi-opaque.

(2) Magnifying Glass: The glazes all contain many fine bubbles. A few of the bubbles are larger than the rest.

Conclusions.—As would be expected, the glaze made with Kentucky ball clay tends to overfire a little sooner than the glazes made with either North Carolina or Florida kaolin. There seems, moreover, to be a eutectic action between the glaze made with North Carolina kaolin and the glaze made with Kentucky ball clay as shown by the fact that B-9 tends to overfire at a lower temperature than either B-7 or B-10. This same action, however, is not noticeable between the ball clay and the Florida kaolin, nor between the latter and the North Carolina kaolin. There is practically no difference in the color of the glazes. In this series, as in series A, the glazes fired in the Dressler kiln with a short firing period are much superior to those fired in the periodic kilns, even though the firing temperature is much higher in the former case.

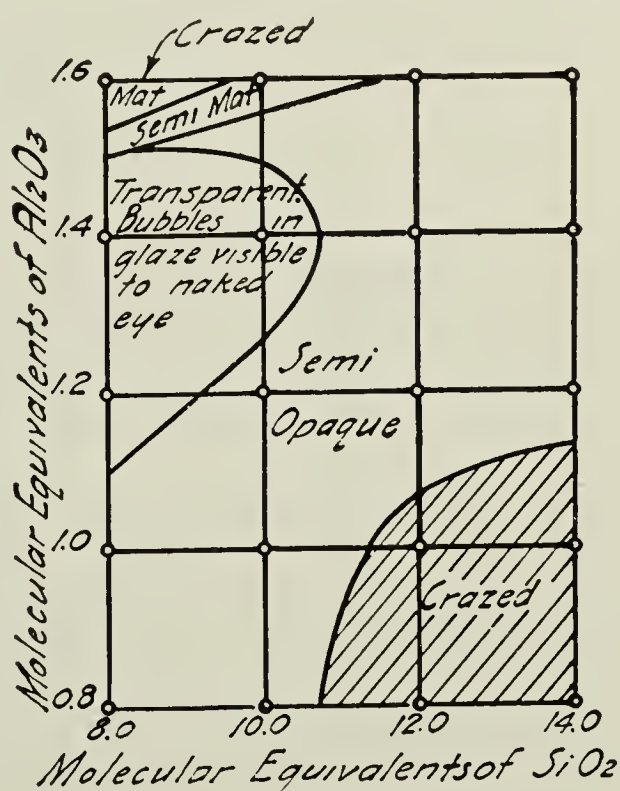
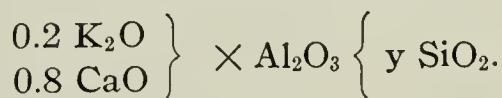


FIGURE 5

General Glaze Formula



Series C

Porcelain glazes maturing between cones 9 and 12 usually contain theoretically nearly 0.3 of an equivalent of K_2O . This figure was naturally used by the writer in his previous work on high temperature glazes. There are, however, some grounds for questioning whether this is not too high

an alkali content for temperatures between cones 17 and 20. Accordingly, a series of glazes was made in which the RO was held constant at 0.2 equivalents of K_2O and 0.8 equivalents of CaO , while the Al_2O_3 was varied between 0.8 and 1.6 equivalents, and the SiO_2 between 8.0 and 14.0 equivalents. (Figs. 3 and 4.)¹

Appearance of the Fired Glazes

Cone 18¹/₂, Dressler Kiln, 31-Hour Burn.—(1) Naked Eye: The results may be best understood by reference to Figs. 5 and 6. Crazeing occurs

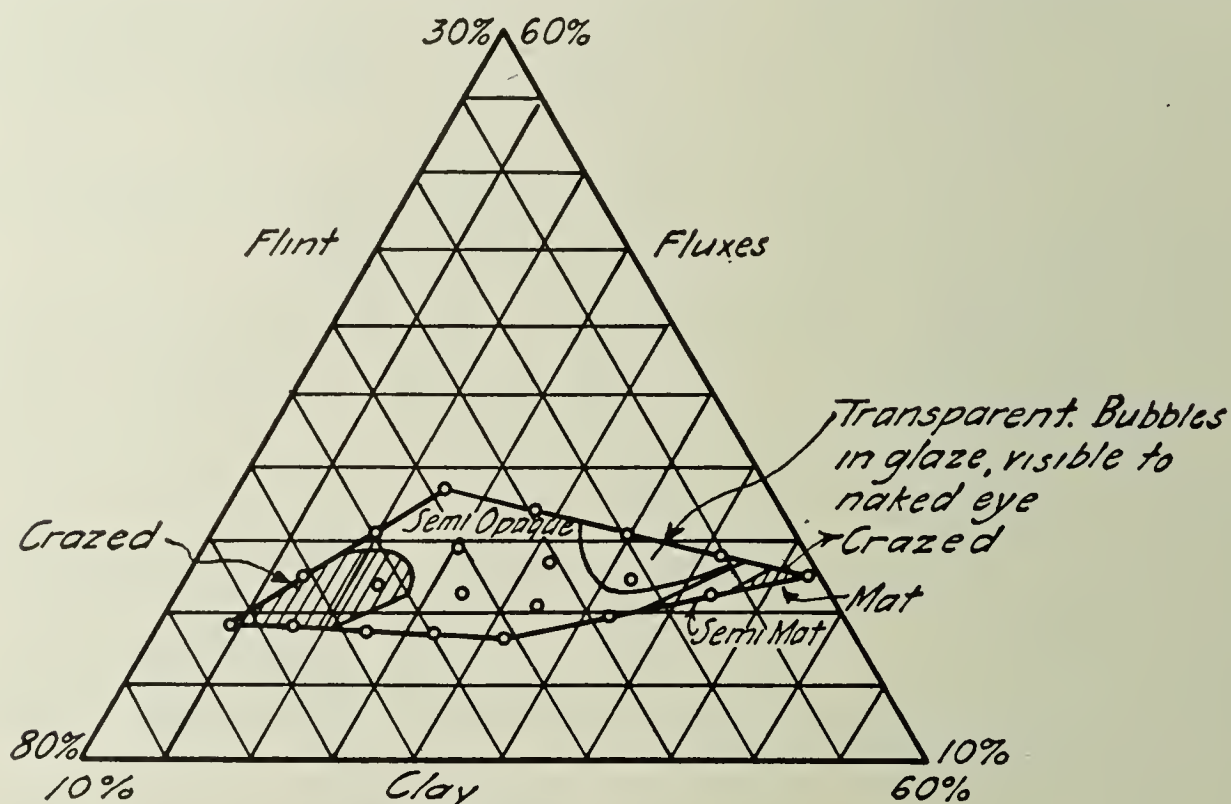


FIGURE 6

Series C. Results at Cone 18¹/₂ Dressler Kiln- 31 Hour Burn

with an alumina:silica ratio of 1:12 and less. This is in the region of high flint. It also occurs slightly with a ratio of 1:5 in the region of high clay. Glaze C-1 with an alumina:silica ratio of 1:5 at 8.0 equivalents of silica is an aluminous matt. The area in the diagram marked "Transparent. Bubbles in glaze visible to naked eye" corresponds to that in the previous article marked² "Smooth, Transparent." In each case

¹ The diagrams for series C are based upon the assumption that the feldspar used was a pure potash feldspar. The actual molecular formulae of the four corner glazes as calculated using the chemical analysis of the feldspar, are shown below:

C-1	0.145 KNaO 0.855 CaO	}	1.67 Al_2O_3	8.6 SiO_2
C-4	0.145 KNaO 0.855 CaO		1.68 Al_2O_3	15.0 SiO_2
C-17	0.145 KNaO 0.855 CaO	}	0.835 Al_2O_3	8.6 SiO_2
C-20	0.145 KNaO 0.855 CaO		0.827 Al_2O_3	14.9 SiO_2

² Twells. *loc. cit.*, 5 [7], 430 (1922).

these glazes are probably approaching overfiring. This is especially true of C-5 which contains many bubbles and has a tendency to sink into the body. The best glazes are those in the area marked "Semi-Opaque," which corresponds to the areas marked "Smooth, Opaque" in the previous article. These best glazes lie approximately between the alumina:silica ratio lines 1:8 and 1:11.

(2) Magnifying Glass: The matt glaze, C-1, has an egg shell surface containing many indentations. The glazes marked "Transparent" contain many large bubbles interspersed with smaller ones. Some of the large bubbles are open at the surface of the glazes. The glazes marked "Semi-Opaque" all contain a great many small bubbles interspersed with an occasional larger one. These larger bubbles increase in number near glaze C-17 in the region of high fluxes.

Cone 19 $\frac{1}{2}$, Dressler Kiln, 31-Hour Burn (Figs. 7 and 8).—(1) Naked Eye:

The results are similar to those already described at cone 18 $\frac{1}{3}$. The area of crazed glazes in the region of high flint has decreased somewhat. Their alumina:silica ratio is now about 1:13 or less. The char-

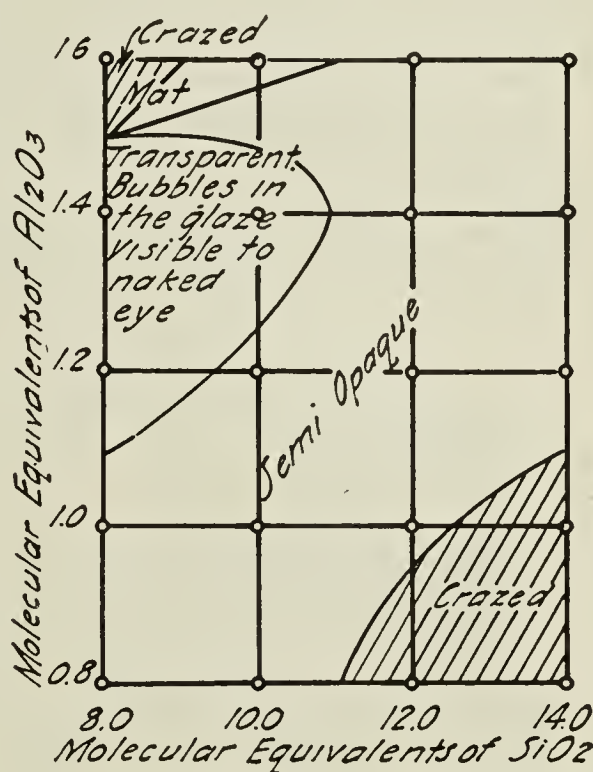


FIGURE 7 SERIES "C"

General Glaze Formula

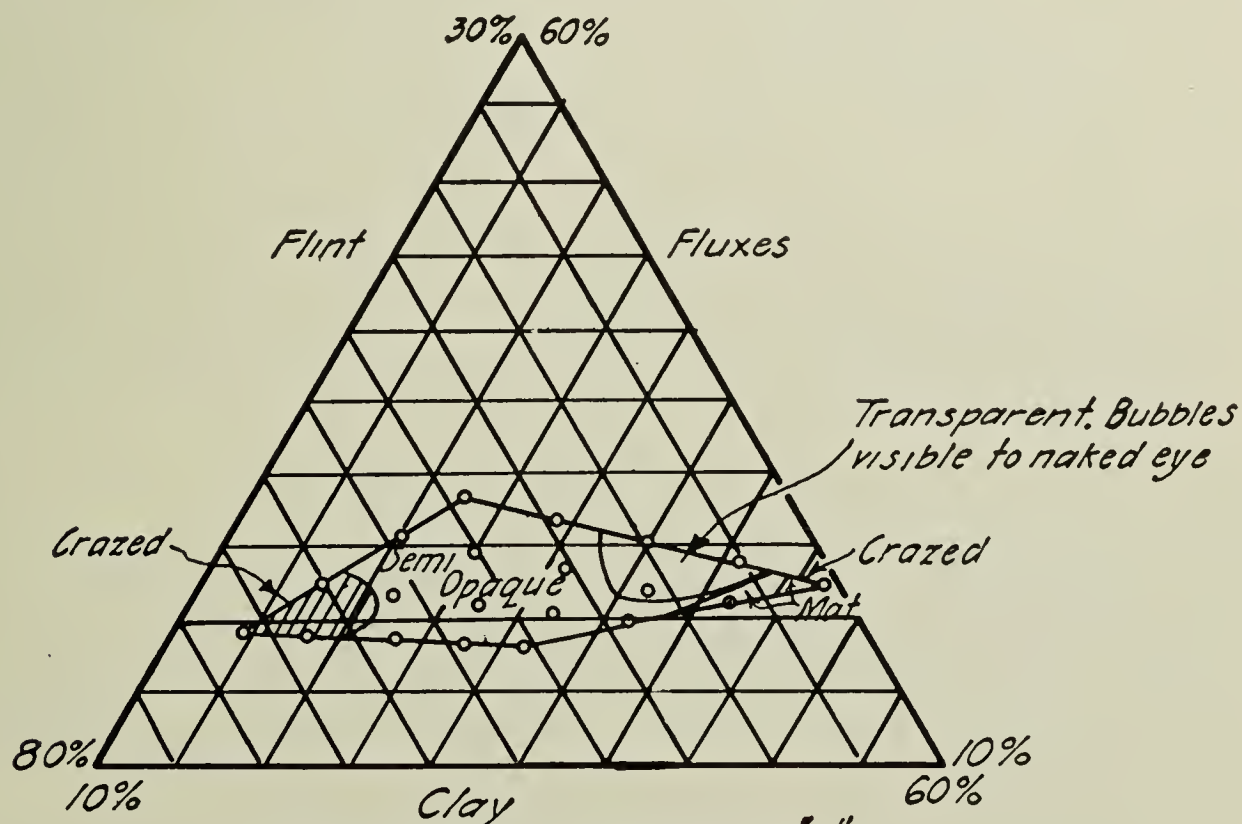
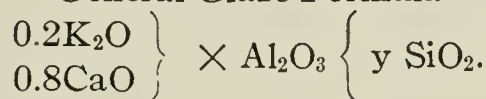


FIGURE 8 SERIES "C"

Results at Cone 19 $\frac{1}{2}$. Dressler Kiln 31 Hour Burn

acter of the crazing of C-16 has changed from fine to coarse. The area of matt glazes has extended to include C-2, which is next to C-1 in containing a high percentage of clay. Glaze C-5 is more nearly over-fired than at cone $18\frac{1}{3}$. The area of the best glazes lies probably between an alumina:silica ratio of 1:8 and 1:12.

(2) Magnifying Glass: The results are similar to those already described at cone $18\frac{1}{3}$.

Cone 19 Flat, Dressler Kiln, 46-Hour Burn (Figs. 9 and 10).—(1) Naked Eye: The crazed and matt areas are similar to those at cone $19\frac{1}{2}$.

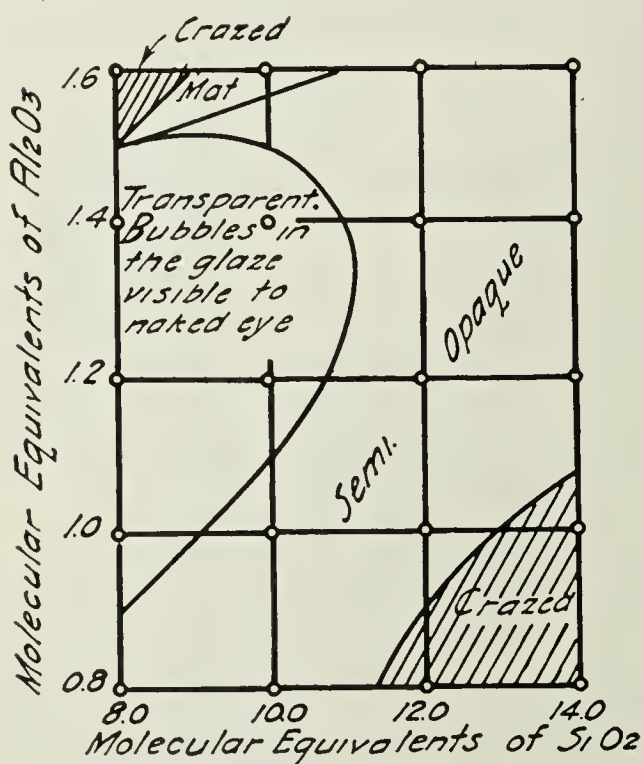
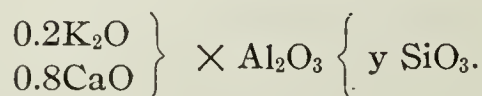


FIGURE 9

General Glaze Formula



parent,” and in the glazes with the highest percentage of fluxes. This is not true of the open bubbles at the surfaces of the glazes. These seem more frequent at cone $18\frac{1}{3}$ than at the two higher temperatures.

Conclusions—For temperatures ranging between cone $18\frac{1}{3}$ and 19 flat, a glaze with an RO of $\left. \begin{matrix} 0.2 \text{K}_2\text{O} \\ 0.8 \text{CaO} \end{matrix} \right\}$ should, as a rule, have an alumina:silica ratio between 1:9 and 1:11 for 8.0 to 14.0 equivalents of silica. These limits do not include C-3, C-4, C-7 and C-12, all of which are good glazes. In fact, under these conditions, the best glazes for general appearance in this series are C-4, C-7, C-8 and C-11, whose approximate limits of compositions are:

Feldspar	9.5 to 12.0%
Whiting	7.0 to 8.5%

Clay	27.5 to 31.5%
Flint	50.0 to 55.5%

The chief change at this temperature is in the area of the transparent glazes, which is extended in the direction of the high flint. Glaze C-5 is badly sunken into the body. The other glazes in this area are also near overfiring. Glaze C-16 acted peculiarly under these firing conditions. The disagreement between the body and the glaze was so great that the glaze actually split off, taking a thin layer of the body with it; yet the glaze is crazed. The area of the best glazes is somewhat reduced in size. It extends from an alumina:silica ratio of 1:9 to 1:12.

(2) Magnifying Glass: The results are similar to those at cone $18\frac{1}{3}$ except that on the whole the bubbles are larger and more apparent, particularly in the region marked “Trans-

This area does not fall near the similar area already picked as containing the best glazes with 0.3 equivalents of K_2O .¹ This is not due as much to actual differences in the appearance of the two-glaze series as it is due to changes in the methods of studying the fired glazes. As a matter of fact, considering the difference in grinding, the results obtained with 0.2 equivalents of K_2O coincide closely with those previously obtained with 0.3 equivalents of K_2O . In the latter case the writer would now pick as the best glazes those with higher equivalents of alumina and silica than he did previously. This would make the best glaze areas in the two series practically coincident.

As has already been stated, relatively little difference can be detected

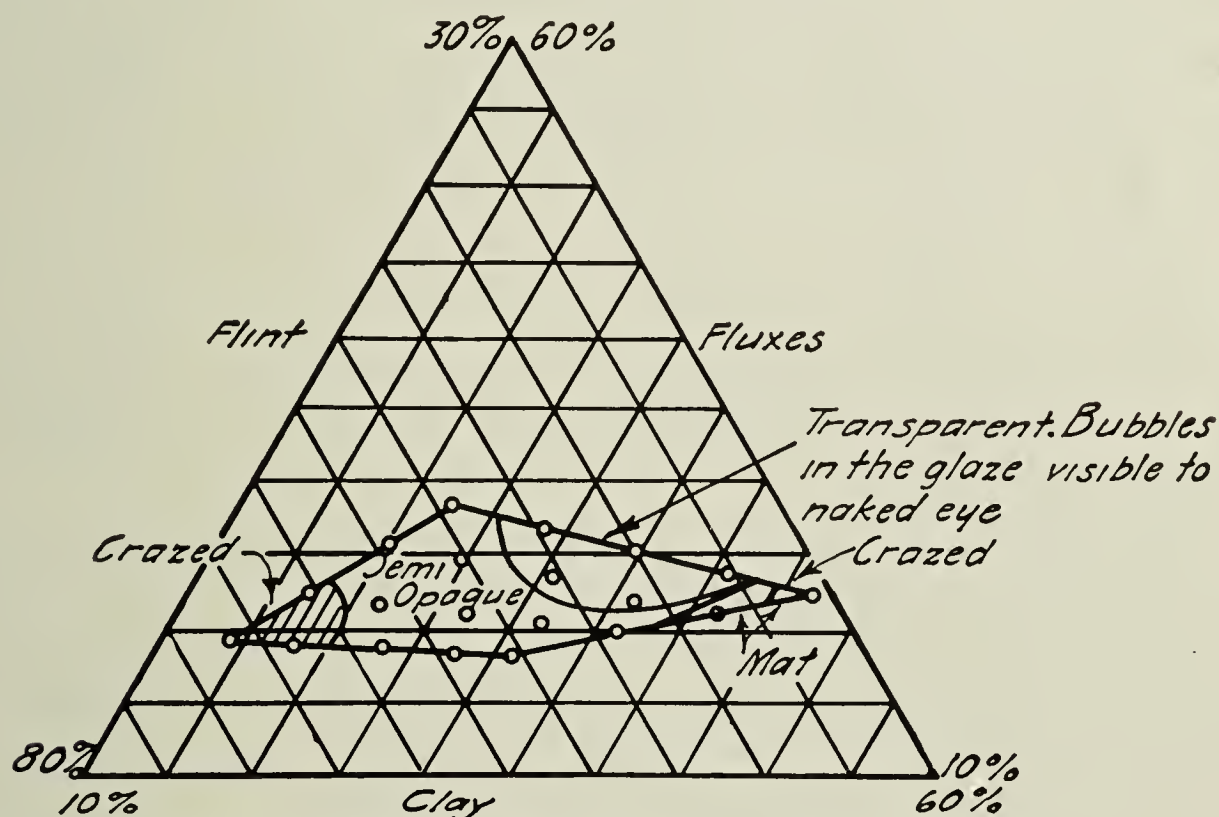


FIGURE 10
Series C. Results at cone 19 Flat. Dressler Kiln.
46 Hour Burn

between the glazes containing 0.3 K_2O and 0.2 K_2O . The latter seem more transparent although this may be due partly to having been ground for a longer time.²

General Conclusions

In the proper development of a glaze the firing conditions are of the utmost importance. The kind of kiln, the firing curve, the cooling curve, and the nature of the kiln gases, all greatly affect the resulting structure and appearance of the finished glaze.

¹ Twells, *Jour. Amer. Ceram. Soc.*, 5 [7], 439 (1922).

² This agrees with the opinion of Emile Bourry, "A Treatise on Ceramic Industries," p. 436, 3d. ed.

TEMPERATURE CONTROL OF DRESSLER TUNNEL KILN¹

BY T. R. HARRISON

ABSTRACT

The method of graded adjustment of fuel supply was adopted. Adjustments to compensate for variations in quality of fuel gas, which often amounted to as high as 30% change in the gas pressure at the burners within two or three minutes, are produced through the agency of the variation in the length of a bunsen burner flame as different kinds of gas are supplied under the same pressure. The adjustment is thus made without the temperature departing from the desired value.

Further minor adjustments are made according to slight departures from normal of the combustion chamber temperatures. The pyrometer control contacts are moved away from the normal position simultaneously as the gas pressure is adjusted, the magnitude of this adjustment being proportional to the necessary motion of the contact points to bring them to the momentary position of the pyrometer pointer. The contact points are then automatically returned to their normal position at a predetermined (constant or variable) rate which is the estimated rate at which the kiln should return to its normal value when the correct adjustment has been made. A sufficient correction is thus made promptly without over-correction during the necessary period of recovery as demanded by the kiln lag.

Introduction

Conditions to be considered in firing the Dressler tunnel kiln of the Champion Porcelain Company include temperature at hottest section along tunnel, length of heat zone, and analyses of the tunnel gases at various points.

On account of the large volume of the kiln, and the necessity of holding the flames of the main burners as long as possible in order to produce a long maturing zone, no serious consideration was given to the most popular method of temperature control whereby the heat supply is operated intermittently between a high and low value. Other considerations entered also, for example, the fact that most of the combustion air is forced into the kiln past the exit cars, preheating the air and cooling the cars. Even if this could be controlled along with the gas it would be most likely to produce surges of gases up and down the tunnel, disturbing the delicate balance which maintains the proper distribution of tunnel atmosphere.

The most serious condition to be met in firing this particular kiln is the variation in quality of the city gas which is used as fuel. At times this may be coal gas or coke oven gas and at other times water gas or mixtures of the two. As compared with hydrogen, the density of the coal gas is about 5.9 and that of the water gas is about 8.8.²

Variations in Gas Supplied

Curve A, Fig. 1 indicates the variations which occurred in the density of the gas as supplied to the kiln during one twenty-four hour period.

¹ Presented by J. A. Jeffery, Summer Meeting, AMERICAN CERAMIC SOCIETY, Detroit, Aug., 1923.

² The figures here given are not exact in all cases.

Coal gas has lower density and hence under given conditions of valve opening and pressure the flow would be about 20% greater than with water gas, and since the heating value of coal gas is greater also, these conditions combine to raise the temperature of the kiln when coal gas follows water gas.

Methods of Control

In order to maintain the temperature constant the gas pressure at the burners must be varied according to the gas changes as indicated by curve B. Curves A and B are taken from the charts of recording meters. Sketch C shows the piping arrangements of the gas supply line with the main

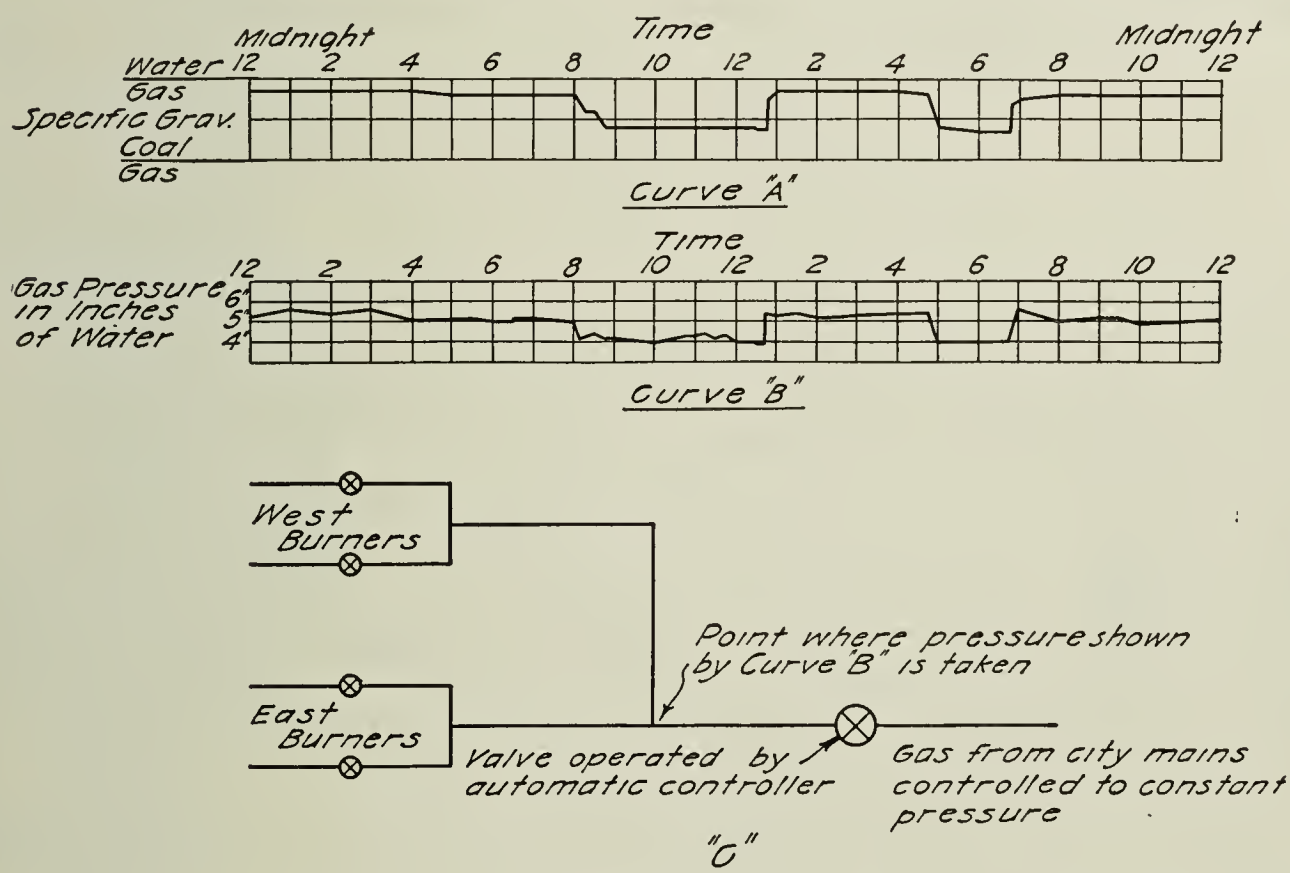


FIG. 1.

control valve, the connection to the pressure gage and the burners and valves. These individual burner valves are adjusted separately to permanent positions.

The Controller.—The main burden of the controller is borne by a part of the mechanism which operates the control valve according to changes in gas quality. This operates accurately enough so that the temperature of the kiln would hold fairly constant without further adjustment as is shown by comparing curves A and B of Fig. 1. It will be seen that when the specific gravity of the gas changes, the controller makes a proportionate change in the gas pressure and the pressure is further adjusted only very slightly by another mechanism, operating according to temperature, to maintain a constant temperature within the kiln.

Control of Variations not Due to Gas Quality.—A slight waviness

is observed in the pressure at times when the gas is of constant quality, this being clearly seen between midnight and 8 A.M. These smaller adjustments are made by a part of the controller which operates when the temperature tends to drift away from the desired value. These waves agree in period with the schedule of the cars, this agreement holding quite consistently.

Control of Variations Due to Gas Quality.—Figures 2, 3 and 4 show the principle of operation of that part of the controller which operates according to gas quality. This makes the necessary adjustments so promptly after the quality changes that the temperature makes practically no deviation from normal.

The Bunsen Burner Basic Means of Adjustments.—The flame of a bunsen burner is the basic means of making these adjustments. When



FIG. 2.

Water gas
Coal gas
Bunsen flames

a bunsen burner is supplied with gas from the mains the length of the flame and of the central cone will vary according to the quality of the gas. While the rate of flame propagation in the gas is doubtless different for different kinds of gas, the more important causes of the difference in flame length are probably viscosity, or rate of flow, and the amount of air required for combustion.

As compared with water gas, coal gas requires about 10% more air for combustion and about 20% more gas flows through the burner, hence the increase in flame length would be about equivalent to what would be caused by increasing the flow of any one kind of gas by 30% without increasing the air.

A burner supplied with gas at uniform pressure will burn with flames as indicated at 1 and 2 (Fig. 2) when supplied with water gas and coal gas. At 3, Fig. 3, is indicated the principle by means of which a differential thermocouple sets up currents which operate to bring the couple to a definite position with reference to the length of the flame.

Figure 4 shows the manner in which this is accomplished while simultaneously making a suitable change in the setting of the gas valve.

To illustrate the operation let it be assumed that the gas is changing to a higher proportion of coal gas at 1, this makes a longer flame, cooling the lower junction and heating the upper junction of thermocouple 2, thus setting up a thermoelectric current as indicated by the arrow. This causes galvanometer 3 to deflect and operate a relay which turns disc 4 (shown in solid line) in the direction indicated. Disc 4 rotates lever 5 and thus raises the couple until both junctions again come to the same temperature.

Disc 4 also moves electrical contact 6 away from dead point 7 into elec-

trical contact with segment 8H. This contact energizes the valve operating mechanism 9 which commences operating to partially close the main gas valve by means of sprocket 10.

Simultaneously mechanism 9, being belted to the disc 11 (shown dotted) which carries segments 8H and 8L, will rotate disc 11 until dead point 7 again reaches contact 6 and the operation will be stopped.

Thus the amount of adjustment of the valve will be proportional to the change in length of the flame.

Maintenance of Constant Kiln Temperatures

As already indicated, finer adjustments must be made from time to time to correct any tendency for the temperature to drift away from the normal value.

For this purpose six thermocouples are placed with their junctions between the double walls of the combustion chambers, three couples on either side. These are placed several feet apart along the hottest section of the chambers and register promptly any drift in the temperature, adjusting the valve to correct the condition.

The couples are connected in series, making the apparatus six times as sensitive and causing the controller to operate to keep the average temperature of all six couples constant rather than controlling according to the temperature at any one point.

Corrections are made so promptly that the average temperature of the chambers usually stays constant to within plus or minus two degrees centigrade.

The operation of this mechanism will be explained by considering the case where the kiln begins losing temperature.

Referring to Fig. 5, if the temperature starts to get low the galvanometer pointer 1 makes electrical contact with point 2L. This energizes the mechanism 3 to turn sprocket 4 and open the gas valve. Mechanism 3 also turns bevel gears 5 and arm 6 which carries the contacts 2H and 2L. This operation continues until arm 6 has moved as far as the pointer moves, then operation ceases. Thus the gas is increased proportionally to the error in temperature, enough for recovery and no more.

Kiln lag causes temperature recovery to be slow. When arm 6 is moved

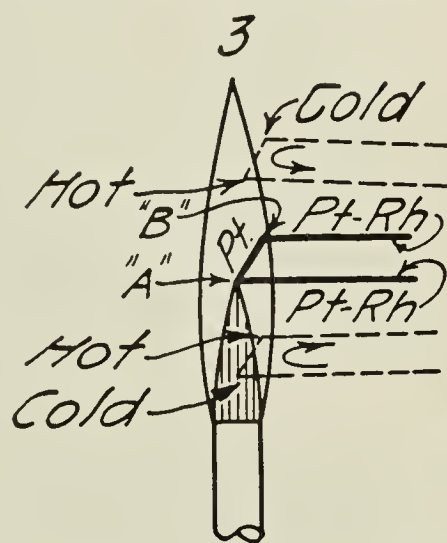


FIG. 3.—A differential thermocouple operates to hold its lower junction on the top of the inside cone of the flame, raising or lowering with the changes in gas quality. Thermoelectric current flows in direction of arrow when couple is too high. No current flows when junctions A and B are at the same temperature. Current flows in opposite direction when couple is too low. Thermoelectric currents deflect galvanometer and operate mechanism to bring differential couple to the central position. This also moves a contact which causes the gas valve to be opened or closed.

away from its normal position N an escapement mechanism 7 automatically returns it to N at a slow rate without moving the valve. There is no further valve adjustment as long as the kiln returns to its normal temperature at this same rate.

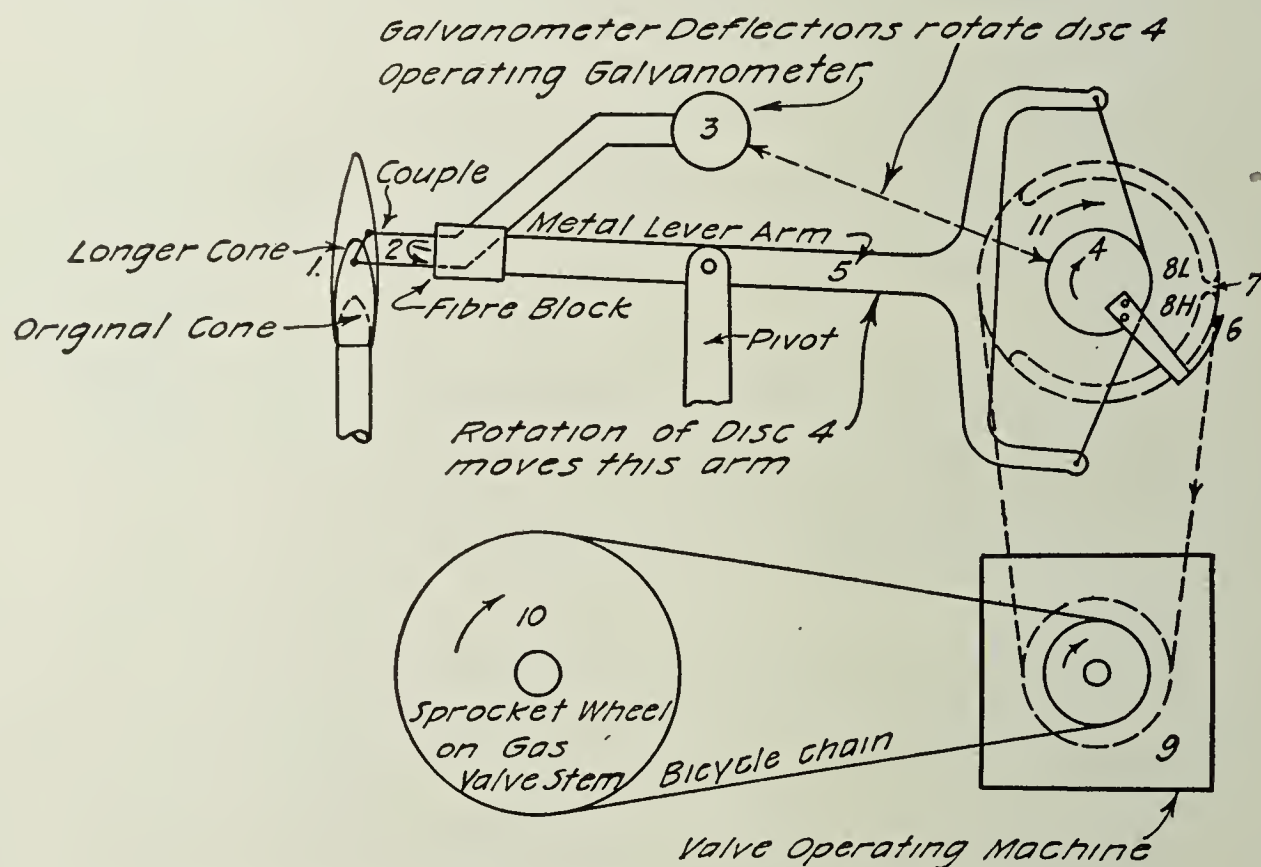


FIG. 4.—Mechanism for controlling gas pressure according to quality.

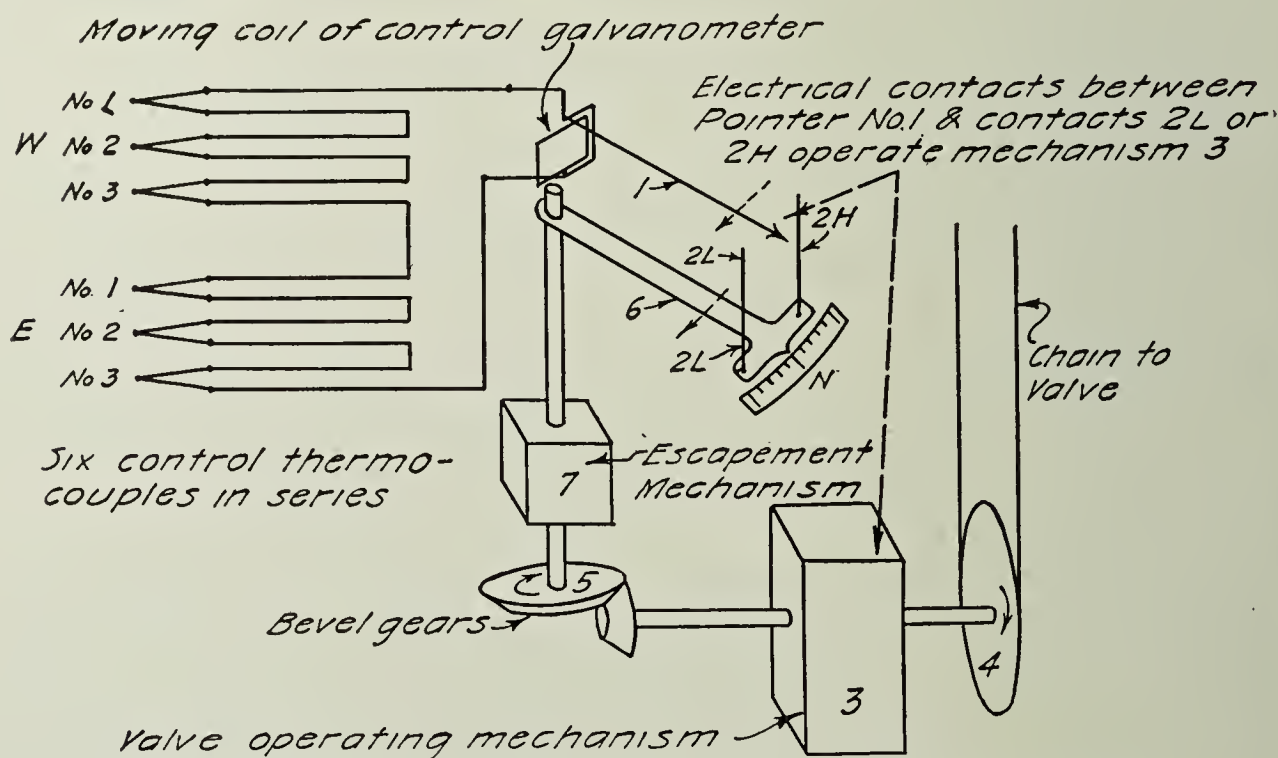


FIG. 5.—Additional control of gas according to kiln temperature.

If the temperature recovers more rapidly than the rate of return of arm 6 contact will be made between points 1 and 2H, operating to reduce the valve opening, so that by the time the normal temperature has been reached the gas pressure will be properly adjusted to hold it there.

On the other hand, if the temperature recovers too slowly the escapement will cause contact to be again made at $2L$ and thus open the valve more. Thus enough correction will always be made to return the kiln to its normal temperature but the mechanism operates to prevent the temperature going too far in the other direction.

The movable arm 6 and escapement mechanism 7 are additions to a standard temperature controller which make it operate successfully on a kiln having such a long lag. Before these additions were made the standard machine would cause the pressure to vary continuously, sometimes going up and down between 2 inches and 7 inches with constant gas quality. Even setting the escapement mechanism 7 to operate three times as rapidly as it now does caused the gas pressure to "hunt" over a range of $1\frac{1}{2}$ inches.

The machines shown in Figs. 4 and 5 are combined to operate upon the same valve by means of a suitable switching arrangement and clutches.

Gas Control by Pressure

In a new controller now being designed the gas will be controlled according to its pressure rather than the valve setting. This will then compensate for variations in the pressure of the supply gas without waiting for the temperature to be affected and will also eliminate inaccurate adjustments caused by back-lash in valves.

The new controller will control the air supply in conjunction with the gas. Also, pyrometers near the ends of the combustion chamber flames will operate the air supply to maintain a constant length of flames and heating zone, making corrections for variations of fan speed, temperature of intake air, and other variables which cause irregularity in the oxygen supply.

At present it appears most probable that the gas for the main burners will be controlled according to gas quality and combustion chamber temperature; the "auxiliary" or tunnel gas according to gas quality and analysis of tunnel gases, and the air or oxygen will be controlled according to gas quality (only slight adjustment believed to be required), combustion chamber temperature in hottest section (varying with equivalent adjustments of gas of constant quality) and combustion chamber temperature near the ends of the flames, the latter maintaining the correct ratio between gas and air throughout the various conditions surrounding the kiln in its continuous operation.

NOTE ON THE HEAT DISTRIBUTION IN UPDRAFT KILNS¹

BY A. V. BLEININGER

ABSTRACT

In the pottery updraft kiln the rising gas currents tend to separate into distinct streams which follow the lines of least resistance in making their exit through the kiln crown. The draft while weak at first becomes very strong during the heat raising period and emphasizes the vertical stratification of the gases. In using natural gas as fuel complete combustion is not usually attained during the period of maximum firing and CO is invariably found present.

The irregularity of the heat distribution is chiefly due to the formation of distinct gas currents and the long soaking of the top in order to secure proper heating of the bottom. Remedies proposed are slower raising of the heat in order to secure top and bottom temperatures more nearly equal and reducing the time of the soaking period which is often excessive; the use of dampers for the control of the draft; and the employment of low pressure forced draft. It is believed that in the future the application of positive pressure will prove most effective in securing more economical firing in all types of periodic kilns.

Introduction

The Kiln.—The problems of heat distribution are no less complex than those of heat generation and they are particularly so in the updraft kilns of the pottery industries.

We are dealing here with bisque kilns which are 18 ft. in diameter and have a height of 13 ft. to the shoulder of the crown which has a rise of 3 ft. The glost kilns have a diameter of 16 ft. 6 in., a height of 14 ft. to the shoulder of the crown and a rise of 2 ft. The bisque kilns have a capacity of 3750 and the glost kilns of 3300 cubic feet and are fired with natural gas. All of these kilns have ten furnaces and the gases as they emerge from the furnaces are split into two streams, one of which goes under the floor to the well hole from which it rises, and the other ascends through the bag into the kiln space. The exit of the gases is through a ring hole 14 inches in diameter and through 30 slick holes, $4\frac{1}{2}$ by $2\frac{1}{4}$ inches, three of the latter being provided for each furnace. All of these are spaced in the crown fairly symmetrically.

Factors in Heat Distribution

Velocity of the Gases.—The direction of the gases is upward and the heat distribution throughout the five sections known as quarters depends upon the volume and the temperature of the combustion gases, their velocity, the rate of firing and the duration of the soaking period.

It is obvious that the velocity of the gases is slow at first due to the sluggish draft. It then increases until it may become excessive toward the end of the burn. This raises the interesting question as to the relation

¹ Presented before Whitewares Division, Pittsburgh Meeting, Feb., 1923.

between the velocity of the gases and the heat transmitted and as to whether it conforms in general to Reynold's law:¹

$H = At + Bdv t$, where

H = heat transmitted per unit time and per unit surface,

A and B are constants,

d = density of the heat carrying fluid,

v = velocity, and

t = difference in temperature between the heat carrying medium and the surface.

While this law seems to apply satisfactorily to many conditions of heat transfer its constants remain to be determined for the conditions existing in ceramic kilns.

Time Factor.—It is evident also that the time factor as in all heating processes is exceedingly important. This involves both the rate of heating and the time one portion of the kiln is held at a constant temperature in order to reach the desired heat intensity in another. The top of the kiln setting usually reaches the maximum temperature first and by soaking it is caused to extend to the bottom, a procedure which is assisted by the increasing heat accumulation of the kiln floor. The increasing thermal conductivity of the saggers with temperature is also a factor to be considered. The method of first obtaining the maximum temperature on top is by no means desirable and it would be much better if we could maintain smaller temperature differences from the beginning of the firing. This would avoid, to a considerable extent, the long period during which the ware in the top of the kiln is exposed to the higher heat with the result that the amount of too hard-fired ware would be decreased. The reverse would, of course, hold for the ware in the bottom of the kiln. By regulating the admission of air through the furnace door and two openings, one immediately above the burners and one leading to the bag, it is possible to regulate the flow of the hot gases to the center of the kiln to some extent. But usually the main object of many firemen is to reach a safe maximum temperature on top and to hold it until the heat soaks down. It would be better to work the heat to the center as early as possible so as to maintain a smaller temperature difference between the two extremes.

Excess Air.—It is a curious fact that the heat penetration to the center is brought about more readily with coal than with natural gas. As the firemen say the bisque fires more "solid" with the former fuel than with the latter. Natural gas is by no means an easy fuel to use from the standpoint of complete combustion. Its high requirement of oxygen is difficult to meet when the heat is being raised fast and large volumes of the gas are introduced. This has been shown by gas analyses made by us, the results of which are given in the following table:

¹ *Proceedings Manchester Lit. and Philosoph. Soc.* (1874).

Time, in hours	3	6	9	10	13	18	20	22	23
Per cent air	336	220	190	222	129	102	108	104	114

Time, in hours	28	30	32	36	40	45	49
Per cent air	194	180	146	158	158	230	209

Here the values for the per cent of air given stand for the total percentage of air admitted, 100% being the normal amount for complete combustion. The figure 336 hence represents an excess of air of 226. As a matter of fact any value below approximately 125% represents reducing conditions, since it is inconceivable that the mixture of gas and air is so complete with the ordinary mushroom burner that complete combustion can take place with the theoretical amount of air. This is substantiated by the fact that carbon monoxide was always found with any total air percentage below 130–125. The above figures show then that there is incomplete combustion between the 12th and the 24th hour, that is during the period when the heat is being raised. This condition was overcome to a considerable extent by replacing the three burners used in each furnace mouth by five, with an equivalent of gas orifice area, thus increasing the proportion of primary air. Once carbon monoxide is formed the velocity of the gases is such that combustion of this gas becomes very problematical. During the soaking period the amount of air admitted becomes quite large in the effort to distribute the heat throughout the kiln.

Soaking.—The duration of the bisque fire is from 48 to 50 hours, of which from 12 to 18 hours may be spent in soaking. The glost firing consumes 28 hours of which about 6 hours are taken for soaking.

Means of Determining Heat Distribution

Absorption.—The question now arises as to what the real heat distribution of the updraft kiln is. This is ascertained for semi-vitreous ware by determining the absorption of the bisque ware taken from various parts of the kiln. Many surveys of this kind have been made by us and as a whole there are found decided differences in heat treatment. Citing a typical case in which 100 pieces of bisque taken from one kiln have been tested we find a minimum absorption of 3%, a maximum of 12.1 and an average of 8.2%. The mean minus variation is 2.5%, the mean plus variation 3.4% and the \pm variation 5.9%.

Specific Gravity.—This reveals rather large differences in heat effect although it should be realized that absorption *per se*, is not a sensitive criterion of heat work accomplished. We have found that the density of the bisque is much more indicative of this and consider the body to have matured satisfactorily when its specific gravity has been reduced to 2.52 or below.

Heat Work Variations

A close study of the kiln conditions shows that there are well-defined areas which differ from each other decidedly with reference to the heat work done, in spite of the fact that the cones in the different quarters show practically no variation, as far as their usual positions are concerned. We find that there are throughout the kiln hot zones of comparatively small area alternating with cooler ones and that there are sections near the bottom of the kiln which are persistently yielding ware fired to a lower degree of maturity.

Streams of Hot Gases.—There are two conditions responsible for this. In the first place we must assume that there are in the kiln, currents or chimneys of hot gases and between these areas of lower temperatures. The updraft kiln as a whole functions like a chimney or stack and its upper portion is necessarily under a minus pressure. As the temperature rises the draft is increased more and more and with it the velocity of the gases. This induced draft causes the streams of hot gases which already have acquired considerable kinetic energy by issuing from the narrow bags, to follow the paths of least resistance and to produce well-defined currents. Such currents cannot be formed so readily in a downdraft kiln where the direction of the gases is completely reversed. We have hence at least eleven of such streams of gases, ten from the ten furnaces and one from the well hole. When coal is used as fuel these zones are less pronounced since the volume of gas produced is larger and meets with greater resistance in making its exit with the result that they fill the kiln space more completely thus tending to wipe out the differential currents.

Variation in Heat Absorption.—In the second place, the time-temperature relation of the various kiln sections differs quite decidedly so that the heat input shows corresponding variations. The outside ring and the top of the kiln obviously absorb more heat and at a higher temperature than the inner rings and the bottom.

Means of Obtaining Better Distribution

The question then arises as to how better distribution of temperature may be obtained. This may be accomplished in three ways.

Longer Soaking.—First, it may be done by a combination of firing in which the heat is driven toward the center earlier in the burn, the top is brought to a lower maximum temperature and the soaking period is lengthened by several hours. By maintaining a lower top temperature the tendency to overfire the ware is lessened and by lengthening the soaking period better distribution of the temperature is assured. Every hour of soaking at a safe temperature means an improvement in the condition of the kiln.

Draft Control.—Second, better control of the draft by means of properly designed dampers is a very desirable factor in the control of the heat distribution. The present methods used for this purpose are usually quite inadequate and fail to check the strong draft which obtains during the last stage of the firing which is responsible for much of the tendency to form the gas currents already referred to. Dampers such as have been designed by S. B. Larkins of the National China Company would do much to overcome this difficulty.

Forced Draft.—A third means of bringing about the desired heat distribution would be the use of a low pressure forced draft system, using an air pressure at the burners of not more than four ounces per square inch. Such a system is already being used by a number of plants and has been reported upon by Thomas B. Anderson of the Pope-Gosser China Co. in connection with the firing of natural gas. This system would mean the complete elimination of the minus pressure within the kiln and the substitution of a positive pressure. In other words, in such a system a large portion of the air required for combustion would be introduced as primary air in the burners, preferably pre-mixed with the gas. This would bring about several desirable conditions. The system would tend to bring about a much more uniform temperature heat distribution during the earlier periods of the firing and thus would shorten the soaking period very decidedly. This should result in a material reduction of hard-fired ware. Again the presence of a positive pressure within the entire kiln space would destroy the tendency toward the formation of the gas currents referred to since it is not possible to conceive of high and low pressure areas side by side when the pressure differences are of the magnitude obtained with the use of forced draft. As a result the gases would be forced to distribute themselves more uniformly throughout the kiln space and the firing should be expected to be more even in every way. Finally, the positive pressure maintained would effectively stop all leakage of air through the kiln walls and while it would result in higher outside wall temperatures the gain in efficiency would be noticeable. The total result hence should not only be a better distribution of temperature but a saving in fuel as well. The latter might be increased still more by the preheating of the air used for combustion in a recuperator which is neither a difficult nor expensive apparatus to install in connection with an updraft kiln.

It is the belief of the writer that forced draft at low pressure is one of the most effective means of obtaining uniform temperature conditions not only in the updraft but other types of kilns as well. At the same time such systems should make it possible to save time and fuel. The use of these firing methods is quite simple to carry out in connection with the use of natural gas and oil but becomes more difficult when coal is the fuel

used. While such systems have been applied to solid fuel with very good success and much credit is due the men who have designed apparatus of this kind still they are not as easy to control as might be desired. It is possible that the use of producer gas to which the air is supplied under pressure offers a solution of the difficulty.

HOMER-LAUGHLIN CHINA COMPANY
NEWELL, W. VA.

OPHTHALMIC GLASS—A NEW AMERICAN PRODUCT

BY ROBERT J. MONTGOMERY

ABSTRACT

Most of the ophthalmic or spectacle glass used in this country was imported prior to 1914. At present very little is imported and the industry is firmly established in the United States. The various glasses used are listed and their defects discussed. The problem of fusing bifocal lenses is covered in considerable detail. Marked improvement has been made in goggle glasses and colored glasses are being standardized. The effect of sunlight on certain clear and colored glasses is given.

Introduction

Definition.—Of the industries affected by the war little has appeared on glass used by the optometrist in spectacle lenses. Not only the clear colorless eye glass, but the various combinations used for fused bifocals, colored glasses, goggle glasses, etc., are of the group known as ophthalmic glass. This type of glass has been classed as optical because of the high precision required in its use, but it has very definite requirements which are quite different from those of optical glass.

History.—Prior to 1914, practically all the ophthalmic glass was obtained from Germany, France and England. It was chiefly blown glass,

TABLE I

Name		N_D^1	ν
1.	A clear crown	1.523	58.0
2.	A clear flint	1.616	36.5
3.	A clear flint	1.66	32.5
4.	A clear flint	1.69	31.0
5.	Goggle glasses	...	...
6.	Amber glass	3 shades	2
7.	Amethyst glass	2 shades	1.523
8.	Blue glass	4 shades	1.523
9.	Crookes glass	3 shades	1.523
10.	Fieuzal glass	3 shades	1.523
11.	Smoke glass	4 shades	1.523
12.	Yellow glass	3 shades	1.523

cut into round or oval discs the size of a lens ready to be reheated and pressed to the desired curvature. The supply of clear crown glass was quite uniform and satisfied the requirements of the manufacturer. The special glasses used in fused bifocal work and the colored glasses were, however, not satisfactory. The optical properties of these colored glasses would vary and colors could not be duplicated near enough to permit standardization of shades. For fused bifocals the manufacturing loss

¹ The optical properties referred to are the refraction index for the D line of the spectrum or N_D and the mean dispersion or ν obtained from the equation $\frac{N_D - 1}{N_F - N_C} = \nu$.

² The dispersion reciprocal for colored glass is usually about 58.0.

was usually great due to defective fusing of the two lenses. The fusing of the colored glass was practically impossible.

The war stopped importation. The clear crown glass, constituting probably 80 to 90% of the total was quite satisfactorily replaced by plate glass modified to raise the index of refraction to 1.5230. The special flint and colored glasses were not so readily produced, although during the past three years much progress has been made in providing a domestic supply of the flint and colored glasses.

Production in America.—America has developed glasses which equal the foreign glasses in all respects. The preceding list gives the more important of the ophthalmic glasses.

Any number of special colors have been introduced in addition to the above but these are the principal ones. A short discussion of each type will be given.

Clear Crown Glass

Manufacture.—Soda lime glass is rolled into a sheet $\frac{1}{4}$ to $\frac{3}{8}$ of an inch thick. This rough rolled (or polished) plate is cut into squares the size of the desired lens. It may be blown into cylinders and flattened but it is hard to make blown glass $\frac{3}{8}$ of an inch in thickness.

Freedom from Flaws.—Absolute freedom from bubbles, cords or striae which can be seen through the finished lens is necessary. Some striae is always found in rolled or blown glass but when it runs perpendicular to the line of vision and not too heavy it does not cause trouble. This point is discussed in detail by H. S. Roberts and J. C. Hostetter.¹

Color.—Exposure to sunlight will noticeably change the color of practically all crown glass. A distinct straw tint develops in a few days. This tint will not increase materially after thirty days of continued exposure. The following absorption figures show the change in a commercial spectacle glass after thirty days' exposure.

ABSORPTION OF SPECTACLE GLASS

Wave length ($\mu\mu$) Color	640 Red	578 Yellow	546 Green	492 Blue-green	436 Blue
Before exposure	3.35%	2.19	0.32	2.77	1.29
After exposure	4.05%	2.01	3.47	6.78	13.51

This color change may be controlled to some extent and has been reduced materially so that after thirty days' exposure it can hardly be measured.

Expansion.—The coefficient of expansion is important. It must be under control as the glass must allow of fusion with the flint glasses without undue strain. A more detailed discussion of this will be given under flint glasses.

¹ *Jour. Amer. Ceram. Soc.*, 3 [9], 750 (1920).

Flint Glasses

Use.—Three flint or lead glasses are largely used for kryptok bifocal lenses, to allow of far and near vision through different portions of the same lens. A small disc of flint glass, curved on one side, is fused on to the crown glass. The difference in index of refraction of the two glasses gives the desired optical effect. The three flint glasses usually used are of increasing lead content having indices of refraction of 1.616, 1.66 and 1.69 as compared with 1.523 for the crown glass.

Fusion of Bifocal Lenses.—The fusing together of two glasses is a delicate operation at best. The fusion of a spectacle lens must be optically perfect. This means that both parts of the finished piece must be practically free from strain and that no fog, bubbles, mechanical dirt or cracks must appear at the surface of contact. The exterior surfaces are ground and polished after the fusion, but the surface of contact between the glasses is beyond reach. The curve on the crown glass must be maintained. The contact surfaces must be free from defects.

Physical Properties and Defects in Fused Bifocal Lenses

Strain.—The flint and crown glasses must so match in expansion that on cooling after fusion the lens will be well annealed and show the least

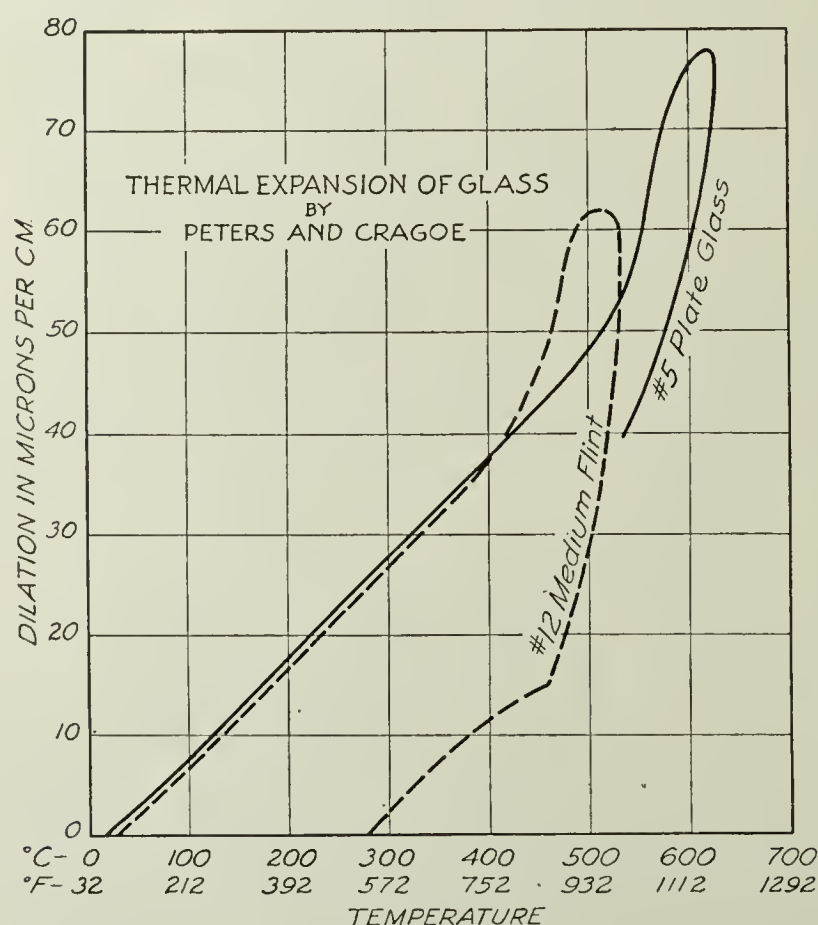


FIG. 1.

We have never been able to fuse together a crown and a flint glass without excessive strain which matched or showed no bend in this drawing test.

¹ *Jour. Amer. Ceram. Soc.*, 4 [3], 219 (1921).

possible strain in polarized light. Fusions of this kind are quite simple when the glasses are of the same general composition and fusibility. The fusion of a hard soda-lime glass with a soft flint glass, free from strain, is practically impossible when both have the same coefficient of expansion, as this property is usually determined. The compatibility of two glasses for bifocal purposes cannot be determined by drawing to a thin thread, two pieces fused together, as suggested by Donald E. Sharp¹ and judging the relative expansion by the bend of the thread.

The expansion of all the glasses tested by Peters and Cragoe¹ was very regular during the first 350° to 500°C. Above this temperature the samples expanded at an increased rate during the next 100° rise. Then a rapid decrease in the rate took place as the glass softened, until finally a contraction was obtained. Figure 1 shows the expansion curves of a plate glass No. 5 and a medium flint No. 12 as given by Peters and Cragoe. These compare closely with the crown and the flint of 1.616 index of refraction used by optometrists.

The temperature for fusing bifocal lenses is 600 to 700°C or at a point where the crown glass becomes fairly soft and the flint glass has reached the deformation or contraction stage. The contraction on cooling is complicated by factors other than the coefficient of expansion.

The two other flints with an index of refraction of 1.66 and 1.69 are still higher in lead content and soften at still lower temperatures giving a greater difference between the expansion curves of the crown and the flint.

W. B. Pietenpol² has shown that the quality of the annealing will affect the expansion especially during that period just before the expansion rate increases rapidly. On the reheating and cooling of a strained strip of glass, a definite shortening was obtained proportional to the strain which had been released. This is found in practice when reannealing badly strained fusions. Arthur W. Gray³ also noticed a failure of the glass to return to its original length after strong heating.

From the above it will be seen that the strain problem is far from being a simple one.

Fog.—A common defect to be found when a crown and a flint are fused together is a surface devitrification. This probably is due to crystals of cristobalite, and is called fog in the factory as it appears as a cloudy surface between the two glasses. It is often very hard to detect and special illumination is usually necessary to show these fine crystals.

There is a decided tendency for flint glass to devitrify. C. N. Fenner and J. B. Ferguson⁴ report devitrification in a light flint glass. They found that chlorides and sulphates cause milkiness due to the formation of crystals of cristobalite. Bowen⁵ gives a rather detailed discussion of the conditions which control crystallization in glass. He found that a medium flint glass shows a surface film at 650°C and an ordinary crown glass shows a surface film at 700°C. Amenomiya⁶ found that crystallization appeared

¹ C. G. Peters and C. H. Cragoe, Jr., "Thermal Dilation of Glass at High Temperatures," *Op. Soc. of Amer.*, **4**, 105 (1920).

² *Chem. and Met. Eng.*, **23**, 876 (1920).

³ *Ibid.*, **21**, 667 (1919).

⁴ *Jour. Amer. Ceram. Soc.*, **1** [7], 468 (1918).

⁵ *Ibid.*, **2** [4], 261 (1919).

⁶ *Jour. Soc. Glass Tech.*, **6**, 231 (1922).

at 700°C and above on ordinary plate glass.

The process of fusing kryptok bifocals is ideal for the development of crystals. The glass is heated to the softening point and held for a considerable period. By careful control of the composition the tendency to devitrify can be decreased and we have found it thus possible practically to eliminate this defect.

In general we have experienced more trouble from fog with the flint glass having an index of refraction of 1.616 than with the ones containing higher per cents of lead. However, with the imported glasses we have had much trouble, all three flints giving surface fog. As the fog is between the flint and the crown it cannot be removed during the final grinding and polishing of the lens.

Bubbles.—When two lenses are fused together gas is often entrapped between the pieces of glass. The resulting bubbles make the finished lens useless. Fortunately losses from this cause are not very large. It is doubtful if the trouble from bubbles can be entirely eliminated.

Perfect cleaning of the glass before fusion and freedom from dust will reduce the loss from bubbles but gas may come from the glass itself at the fusion temperatures and be unavoidably held between the two lenses as the fusion takes place.

We know that a large amount of gas is held in solution in a glass. Cullet will boil almost as much as will a new batch showing that considerable gas is being evolved. Washburn and Bunting¹ actually made an analysis of the dissolved gases which are given off at 1400°C under reduced pressure and found them to be oxygen, carbon dioxide and nitrogen. It is not only at the melting temperature that gas will be evolved. Irving Langmuir² reports that on heating glass to 300°C water vapor is given off. This is progressive, giving increasing amounts up to 450°C. Carbon dioxide and nitrogen were found in another test at 300°C.

It is not unreasonable to assume that gas is given off continuously in increasing amounts as the temperature is increased from 300°C to 600° or 700°C, the temperature at which glasses are fused together. It would be difficult not to entrap some of this gas as the two glasses are fused.

The other defects appearing in bifocal lenses using the three flint glasses are largely mechanical in nature and will not be discussed here.

Goggle Glasses

A goggle glass is one which will give protection to the eye of the workman and must stand ordinary impact without breaking. Two types are on the market. The first is composed of two layers of glass with a film of celluloid or similar material between. A sheet of celluloid is interposed be-

¹ Univ. of Ill. Eng. Expt. Sta., *Bull.* **118** (1921).

² *Jour. Amer. Chem. Soc.*, **40**, 1361–1402 (1918).

tween two sheets of glass, treated with a softener (such as industrial spirits) which causes it to adhere to the glass by the simultaneous action of heat and pressure.¹ A lens of this style was tested, using the method suggested by the Bureau of Standards, by dropping a steel ball 1.59 cm. in diameter a distance of 54 cm. onto the center of the lens. Although it cracked with the first impact, the glass did not give way or fall apart and would have protected the eye.

Owing to the thickness of the double lens and the color of the celluloid the light transmission of the glass is considerably reduced. This is objectionable.

The second method is to take the ordinary lens and harden it by a sudden uniform cooling. This introduces a uniform strain in the glass, making it very tough. It will not break so easily as the celluloid type of lens but when it does crack it does not hold together so well. This idea of hardening was used as early as 1874 by Alfred De La Baste² and has been applied to lamp chimneys and high pressure gage tubes.

A special glass has now been developed which will stand much more than the ordinary laminated or hardened lens and while more expensive is well worth it. A Bureau of Standards test on lenses made from this special glass shows that, when properly finished, they will stand a blow ten times as great as the ordinary goggle lens.

Practically all goggles are of flat glass without curve so the optical properties are unimportant. The index of refraction is usually about the same as that of the regular crown or about 1.523.

Colored Glass

Items 6 to 12 inclusive of Table I give the common colored glasses used by the optometrist. There are many special ones on the market. These trade names mean in a very general way, certain colors and shades but there are no recognized standards. The Bureau of Standards have determined and published the absorption curves for many of these glasses.³ Much of the glass used has been imported and the color and optical properties would vary greatly from shipment to shipment or even in the same shipment. Almost every lens manufacturer has a different source of supply so each have a series of colors which only match those of other plants in a very general way. The color varies with the thickness of the lens and it has been found necessary to obtain the same color in glass of at least three thicknesses to give satisfactory control of the shade. Thus Smoke A shade requires three glasses having shade A color at 2, 4 and 6 mm. in thickness.

¹ *Chem. Abs.*, 12, 986 (1918).

² British patent 2783 of 1874, class 56.

³ Gibson and McNicholas, "The Ultra Violet and Visible Transmission of Eye Protection Glasses," Bur. Standards, *Tech. Paper* 119.

It is quite desirable to make fused bifocal lenses using the various colored glasses for the crown part of the lens. Very few combinations are successfully fused at present. Some progress has been made on this and we hope that before long a complete line of colored glasses will be placed on the market for kryptok fusions.

The most popular color just now is the Crookes glass which is made in three or four shades. It has the property of absorbing a considerable part of the ultra-violet light and has two absorption bands in the yellow at the *D* line of the spectrum.

There seems to be no general agreement among optometrists as to just when each color and shade should be prescribed. The subject is being studied. Now that the glass maker and user are coöperating rapid progress should be made.

Next to the Crookes glass in popularity comes the smokes and ambers. The fieuzals, amethysts and blues are used considerably. Special shades and colors are often used for furnace work, electric welding, etc.

When colored glass is exposed to sunlight for a considerable period there is often a noticeable color change. The following absorption figures are for a sample of commercial amber glass, shade A, before and after being exposed to sunlight for thirty days.

AMBER GLASS SHADE A					
Wave length ($\mu\mu$) Color	640 Red	578 Yellow	546 Green	492 Blue-green	436 Blue
Before exposure	11.71%	12.79	14.29	23.87	46.87
After exposure	14.79%	16.59	18.59	30.55	51.38

The change of color was largely a darkening of the shade as judged by the eye. The color change in amethyst glass made with manganese is well known. The absorption figures given are for a sample of amethyst shade B glass which turned quite blue on exposure to the sun for 30 days.

AMETHYST GLASS SHADE B					
Wave length ($\mu\mu$) Color	640 Red	578 Yellow	546 Green	492 Blue-green	436 Blue
Before exposure	17.55%	30.73	33.59	37.35	23.32
After exposure	20.70%	33.26	34.53	35.99	21.41

The color change to the eye is greater than would be expected from the difference in absorption.

The smoke and the Crookes glasses usually change color. The fieuzal and the blue are the most stable of those we have tested.

This changing in tint makes it practically impossible to match many colored glasses after they have been worn for a time and an effort is being made to stabilize the colors as much as possible. As was shown in the

first part of this paper the clear glass usually changes tint on exposure to the sun. This change in the base glass would naturally change the tint of a colored glass even if the added coloring material itself remained unchanged. There are several colors that will be very stable if a base glass is used which will not change tint to any extent when exposed to sunlight.

Very little of the ophthalmic glass now used in the United States is imported and in many respects this new industry has already progressed beyond the point reached in Europe.

BAUSCH AND LOMB OPTICAL CO.
ROCHESTER, N. Y.

EFFECT OF VARIOUS SIZES OF GROG PARTICLES ON CLAY POTS

BY WARREN S. WILLIAMS

ABSTRACT

The service obtained from refractory clay, glass-drawing pots, 40 inches in diameter, was increased in factory practice by eliminating grog particles finer than 40-mesh.

Introduction

In the manufacture of window glass, by the cylinder drawing machine process, molten glass is ladled from a tank into a refractory clay pot, such as shown in Fig. 1.

These pots are rotatably mounted in a heated draw-kiln by iron pins inserted into the lugs. This design permits a cylinder of glass to be drawn

upward out of the top side of the pot, while the excess glass from the previous draw is melted away by heat on the bottom side. The top is cooled, during the draw, from approximately 2200°F to 1700°F in twenty minutes. At the same time, the bottom is heated over the same temperature range by two diametrically opposite burners in the draw-kiln using natural gas and pressure air. The flames meet and impinge upon the center of the pot and then spread over its bottom surface. This process is repeated continuously

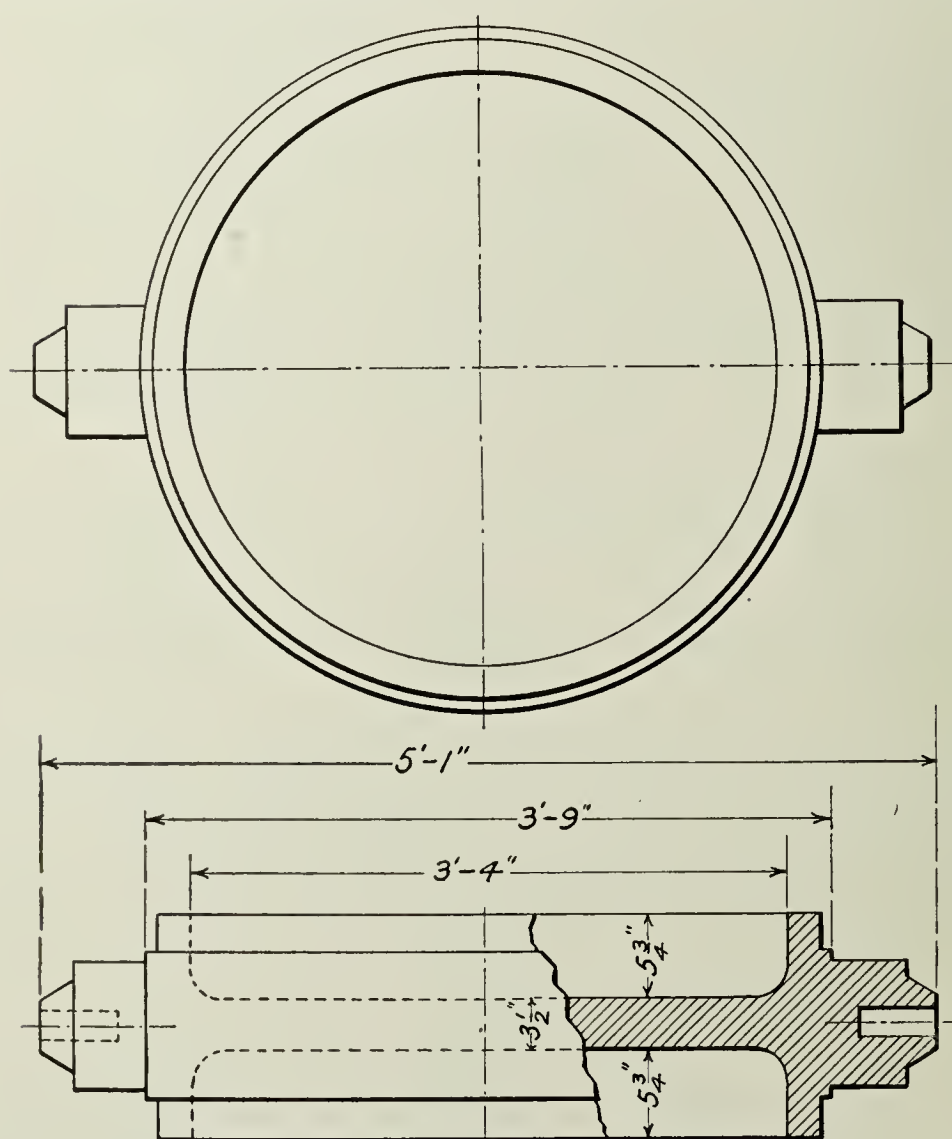


FIG. 1.—Glass drawing pot.

for twenty-four hours a day. On Sunday the pots are left in the draw-kilns and are covered with iron covers, under which they are reversed every twenty minutes. The temperature drop during this period is from approximately 1700°F to 1200°F.

Pot Manufacture

The refractory clay batch for the pots is prepared by mixing the ground materials dry and then shoveling the batch directly into the hopper of an

auger brick machine. In this machine the batch is mixed with water and receives a slight pugging. It is re-pugged several times by the same machine during the aging period.

The pot is built by hand over wooden cores, and weighs approximately 800 pounds when dry. After drying it is burnt in a kiln with a capacity of ten or more pots. When the burn is finished the temperature is dropped to 1800°F. At this heat the pots are transferred to the draw-kilns. Within a few minutes after reaching the draw-kilns a ladle of molten glass, weighing approximately 700 pounds, is poured into them and the drawing operation is started.

Experimental

The service rendered by the pots is reckoned in the number of days in operation in the draw-kilns. During an investigation into methods of increasing this service, experiments were started demonstrating the effect of the size of the grog particle. The batches for this research were made full size in the standard factory manner as previously described. The only variable introduced was the difference in the size of the potshell (grog) particles as given in Table I. Potshell is obtained by chipping the glass away from old pots which have been removed from service. It is 50% by weight of the total batch. The pots made from these batches were full size (Fig. 1) and were manufactured, burned and used in the same manner as standard pots.

The data in Table I was selected from those pots removed from service through failure directly traceable to the clay body, as distinguished from failures due to mechanical operations in the draw-kilns.

TABLE I

Size no.	Size of potshell particles			Through 40-mesh	Total pots used	Pot service Total days in service	Average days in service
	10-mesh	20-mesh	40-mesh				
1	18	29	28	25	86	1639	19
2	21	26	24	29	54	1112	21
3	5	36	30	29	29	639	22
4	66	24	8	2	28	778	28

Results

Those pots made with a greater percentage of finely ground potshell failed largely through knuckle cracks, rim cracks and splitting into halves. These defects were eliminated in a higher percentage of the pots made from the coarser ground batches.

Under comparable conditions as met in large scale factory practice, the practical elimination of grog particles finer than 40-mesh has resulted in increased service from refractory clay, glass-drawing pots.

AN INVESTIGATION CONCERNING THE INFLUENCE OF THE ALKALIES AND ALKALINE EARTHS ON THE FUSION TEMPERATURES OF THE DIFFERENT TYPES OF REFRACTORY CLAYS

By A. S. WATTS¹

ABSTRACT

A summary of results of an investigation regarding the application of Richter's law and its modifications to refractory clays of higher and lower alumina and silica content than previously studied.

The following article consists of a brief summary of conclusions reached by A. L. Donnenwirth, R. S. Kane and E. R. Curry, Ceramic Engineers, 1922, in a study based on Richter's Law "Equal molecular amounts of

basic fluxes have the same effect on clays or kaolins and that the greater the silica content the more effective are the fluxes."—(1868).

Twenty years after Richter, Cramer using Zettlitz kaolin concluded that the effect of the basic fluxes was not widely different when a pure kaolin ($\text{Al}_2\text{O}_3 - 2\text{SiO}_2$) was used but when one-half molecule silica was added ($\text{Al}_2\text{O}_3 - 2.5\text{SiO}_2$) the activity of the flux increased as the molecular weight decreased. The activity was not exactly in inverse ratio of their molecular weights.

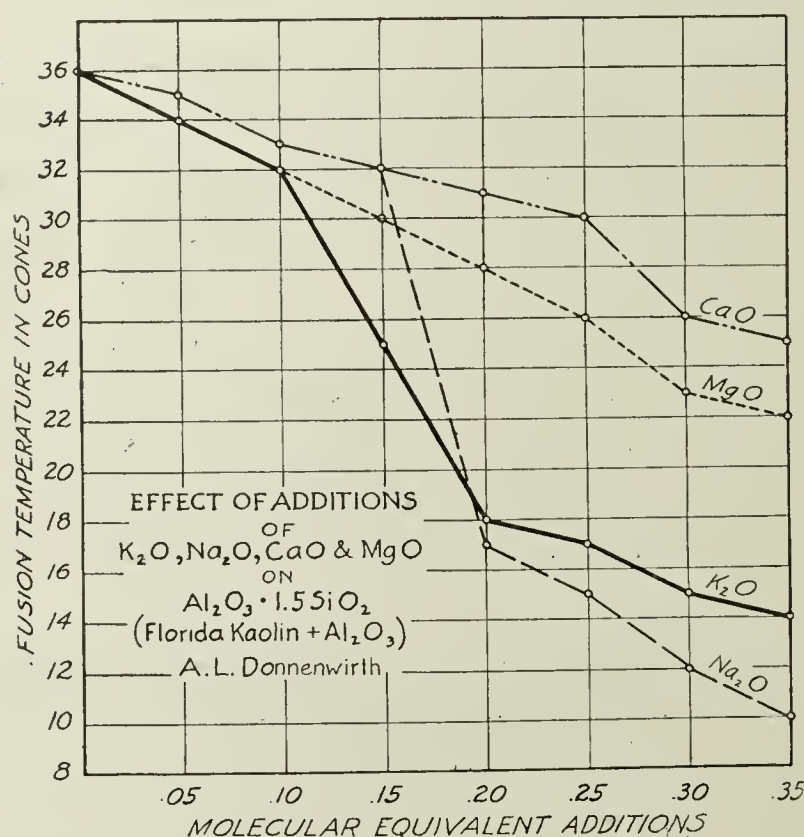


FIG. 1.

Rieke conducted additional investigations with other bases and also checked Cramer's conclusions (*Sprech.*, 198-9, 214-6, 229-32 (1910)).

Montgomery and Fulton,² concluded that with 14 to 18% Al_2O_3 and 86 to 82% SiO_2 , the fluxes display maximum activity.

The Present Investigations

TABLE I

The clay tested was Florida kaolin and its analysis was:

Ignition loss 14.86%; SiO_2 45.67%; Al_2O_3 38.45%; Fe_2O_3 0.75%; TiO_2 0.10%; CaO trace; MgO 0.05%; KNaO 0.06%.

Proportion of Alkalies:

One equivalent of this clay was ground with one equivalent of K_2CO_3 and with Na_2CO_3 in enough benzol to permit molding into balls. The

¹ Presented before the Refractories Division, Pittsburgh Meeting, Feb., 1923.

² *Trans. Amer. Ceram. Soc.*, 19, 303 (1917).

balls were calcined to cone 10. (Seger and Cramer found that subsequent fusions after a cone 10 calcine do not lose over 0.56% alkali.) The clay alkali mixtures were then analyzed with the following results:

TABLE II

	FLORIDA KAOLIN Theoretical per cent	FLUX CALCINE Actual content per cent
K ₂ O	29.61	21.24
Na ₂ O	21.79	16.55

The alkaline earths were added directly as CaCO₃ and MgCO₃. The calcines were next ground with the proper proportions of the raw clay to give the desired compositions, the excess Al₂O₃ or SiO₂ being added to the grind as such.

These mixtures were made into standard size cones and tested against standard cones in an air-gas furnace. The results follow.

The Compositions of Clays Studied

Al₂O₃ 1.5 SiO₂; Al₂O₃ 3.0 SiO₂; Al₂O₃ 5.0 SiO₂.

From a study of the graphs presented, we see:

(1) When the Al₂O₃ exceeds the proportion in the true kaolin formula, the order of activity increases from MgO to CaO to Na₂O to K₂O.

(2) When the SiO₂ exceeds the proportion in the true kaolin formula, the order of activity is reversed and decreases from MgO to CaO to Na₂O to K₂O.

(3) As the SiO₂ increases the activity is increasingly evident.

(4) The increase of activity with increased amounts of fluxes is more pronounced when the Al₂O₃ is in excess than when the SiO₂ is in excess. The presence of moderate amounts of

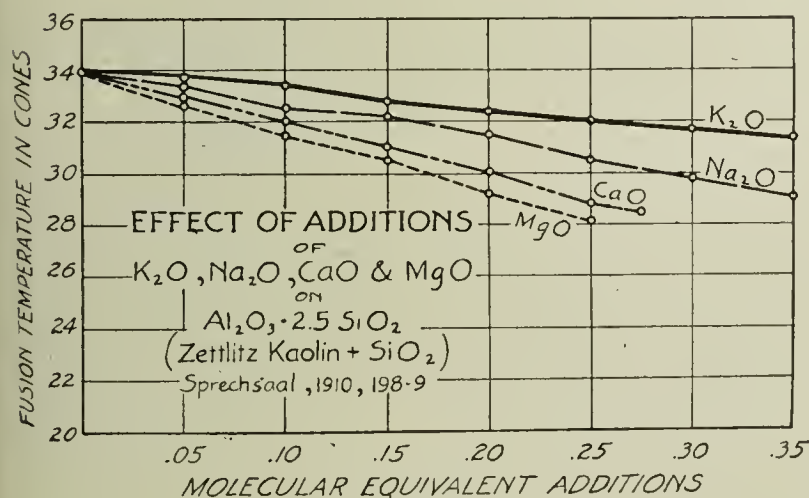


FIG. 3.

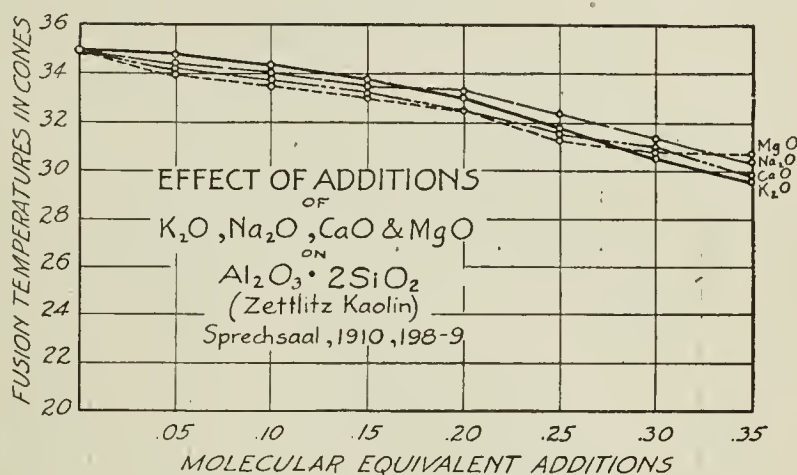


FIG. 2.

fluxes is more dangerous in high aluminous clays than in high siliceous clays.

Discussion

J. S. McDOWELL (Chairman):—At high temperatures silica is so viscous that it has been extremely difficult to determine its melting point. This is now known to be about 1710°C. However, a comparatively pure quartzite will go down at cone 36, corresponding to about 1775°C, which gives a range of viscosity of 65° for pure silica. On the other hand, a certain

mixture of silica with a few per cent of lime or alumina, has a true melting point of 1610° , while the softening point is 1615° , practically the same effect may possibly be brought about by lime and magnesia additions to clays.

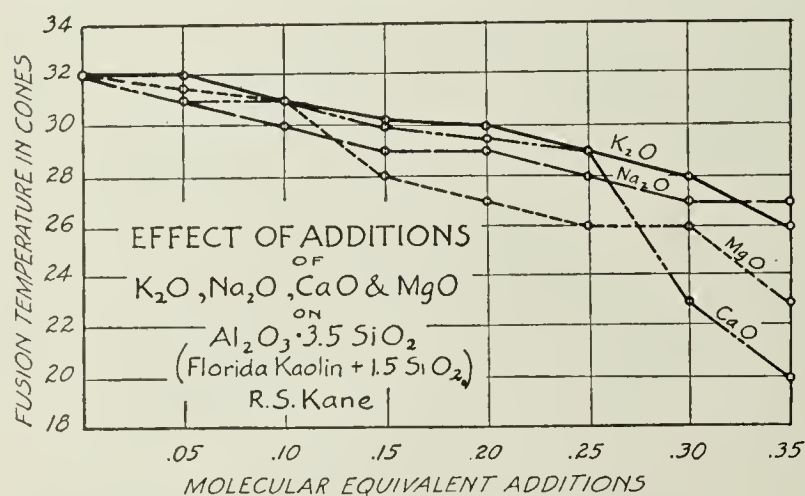


FIG. 4.

high temperature, which corresponds, as I understand it, to these results. That would check up with the fact that the lime reacts very readily with the high alumina refractory. P. H. Bates has called attention to the fact that while lime is active with alumina and therefore high alumina brick will not show up well in a high temperature test with lime, yet the high alumina brick actually give the better service in rotary cement kilns. He attributes this apparent discrepancy to the fact that lime, with the free silica in more highly siliceous fire brick, forms the dicalcium silicate, $2CaOSiO_2$, which dusts at $200^{\circ}C$. He attributes the failure of the rotary kiln brick that are higher in silica to disintegration due to dusting of $2CaOSiO_2$.

A MEMBER:—Is the alkali more active than the alkaline earth?

B. WILCOX:—We always find that the alkaline fluxes are more active.

G. V. McCAULEY:—We have noticed a phenomenon in connection with our Pyrex tanks which has some bearing on this question. The temper-

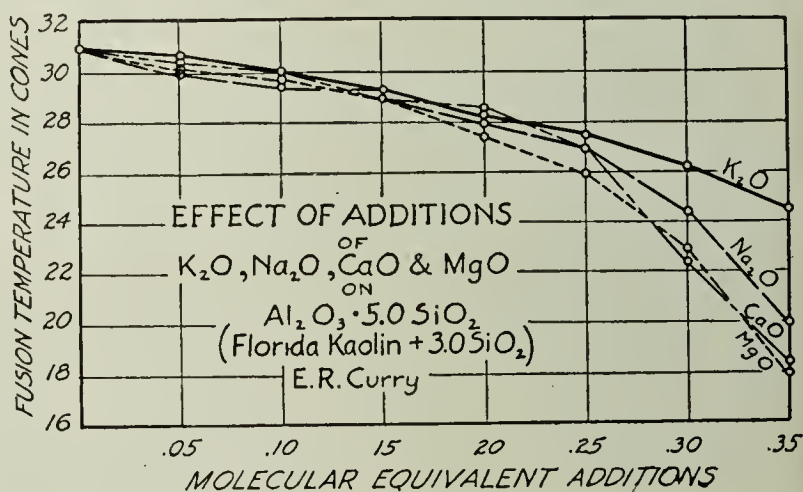


FIG. 5.

atures which we have to run in these tanks are so high that considerable volatilization of soda takes place. As this vapor passes through the checkers with the out-going gas the top of the checker pile is too hot for these vapors to condense; but down near the bottom of the pile these vapors do condense and attack the checker brick at this point. When one of these tanks is let out one finds the bottom checker brick almost gone. By substituting silica for fire-clay brick in the checkers this attack was lessened to some extent.

THE FLINT CLAY SITUATION IN OHIO¹

BY WILBUR STOUT

ABSTRACT

A discussion of the flint clays of Ohio with special reference to Scioto-ville, Lower Kittanning, Oak Hill and Lower Freeport clays. It is shown that (1) flint clay beds of high heat duty quality in Ohio are small but well-defined (2) there is small prospect of finding other deposits under deeper covering (3) the most easily available material is exhausted (4) the present supply will last present plants at least fifty years but will not permit much increased consumption (5) conservation of high heat duty clays should begin now before supply is gone.

Introduction

The flint clays in Ohio are confined to the Pottsville, Allegheny, and lower Conemaugh formations or to that part of the Pennsylvanian system, the rocks of which are largely of marine origin. Deposits economically important are found only in the Pottsville and Allegheny formations as those in the Conemaugh are uncertain in extent and thickness and poor in quality. Both the flint and plastic clays are directly associated with the coal beds or they mark horizons on which coals elsewhere occur. In the Ohio field in small or large quantities flint clay occurs below the Sharon, Anthony, Flint Ridge, Upper Mercer, Bedford, Brookville, Winters, Clarion, Lower Kittanning, Oak Hill, Lower Freeport, Upper Freeport, Mahoning, Mason, and Harlem coals. Of these, however, the only deposits that are sufficiently large in area and have qualities recommending their use for high heat duty refractory ware are found below the Anthony, Lower Kittanning, Oak Hill, and Lower Freeport coals. These members will be considered in regular order beginning with the oldest.

Scioto-ville Clay

The Scioto-ville clay is the second well-recognized clay stratum in the Pottsville formation. It lies on the average from twenty to forty feet above the Sharon coal and approximately the same distance below the Quakertown bed. It is directly overlain by a coal which is known as the Anthony but which seldom attains a thickness exceeding one foot. In Ohio, the Scioto-ville clay of the characteristic flinty quality is confined largely to two districts which are known as the Scioto-ville and the Logan from their proximity to these places. Small outlying patches of flint clay, however, are present in parts of Jackson, Pike, and Vinton Counties.

The Scioto-ville clay is not a persistent bed by any means even in the areas in which it is best developed. It is wanting, however, more through lack of deposition than through removal by erosive agencies subsequent

¹ Presented before Refractories Division, Pittsburgh Meeting, Feb., 1923.

to its formation. It appears to have been formed in swamps which were more or less isolated and which were irregular in outline. It is wanting also over large areas due to the fact that the lower Pottsville members were deposited only in the low troughs and basins in the uneven Mississippian floor. Due to these causes the fields of Sciotoville clay are usually small and the deposits within the areas are irregular and uncertain.

In the Southern Ohio or Sciotoville field the average thickness of the flint clay in the productive areas is from 2 feet 6 inches to 3 feet and the semi-flint clay has much the same measurement. The combined thickness is usually between 3 and 7 feet with a maximum of about 12 feet.

Scioto County.—In a general way, the Sciotoville clay is confined to the eastern half of Scioto County but owing to wants through lack of deposition and through loss by erosion it covers only a small part of this area, in fact, the total known field is not more than thirty square miles in extent. The most continuous bodies of flint clay are found in western Harrison and eastern Bloom townships. In the remainder of the county the deposits are more or less isolated and are usually small, only a few acres in extent.

The western part of the Sciotoville field or that lying between the Scioto and the Little Scioto rivers has been so exhausted by mining for the original plants at Sciotoville and Portsmouth that it is now practically abandoned. Not more than 50% of the clay, however, was removed, for the deposits lay so near the summits of the ridges that the roof was poor. As the flint clay in this area is of excellent quality and as the covering is thin, parts may be mined in the future, when such materials become scarce, by steam shovels. At most the quantity of clay that may thus be recovered would be sufficient only for supplying two or three brick plants for approximately forty years. The cost of such material would be high owing to unprofitable stripping part of the time over old mines and to the expense of transportation which would be by motor trucks. The conditions at best are unfavorable and will not warrant the establishment of new plants. It will probably remain abandoned, as it is at present.

The known area of Sciotoville clay east of the Little Scioto River is less than ten square miles in extent and has been drawn upon since 1870 for high heat duty refractory material. It supplied clay for plants, now abandoned, at South Webster and Sciotoville, and furnishes material at present for two works at Oak Hill, one at Scioto Furnace and two at Portsmouth. The productive area is largely controlled by the present firms whose supplies of material are ample to meet their needs for many years. The blocks of clay not controlled, however, are generally too scattered

or too small to justify the erection of new works. Possibly two or three new plants could be maintained but not more than this. Of the scattered deposits of Sciotoville clay in northern Scioto, western Jackson, eastern Pike, and southern Vinton Counties little need be said as most of them are only a few acres in extent and far removed from lines of transportation. Only two of them are worthy of prospecting for such purposes.

It is thus seen that in the Sciotoville clay field of southern Ohio the supplies of material yet available would not justify the establishment of more than five new plants. It is, in fact, at its maximum and will not be able to take care of increased business in the future.

The flint clay of the Sciotoville field is well within the high heat duty class of refractory materials and is rather constant throughout the field in both composition and physical properties. Typical examples are given in Table I.

TABLE I

CHEMICAL COMPOSITION						
	Per cent		Per cent		Per cent	Per cent
Loss at 105°C	1.35	1.62	P ₂ O ₅	0.02	0.11	
Ignition loss	12.90	12.76	Na ₂ O	.00	.62	
SiO ₂	45.20	45.13	K ₂ O	.52	.76	
Al ₂ O ₃	36.77	34.08	MnO	trace	.01	
Fe ₂ O ₃	1.30	2.35	S	trace	.17	
CaO	0.50	0.25	Total C	0.25	.52	
MgO	.08	.54	Inorganic C	.03	.00	
TiO ₂	1.80	2.08				
Oxide ratio	RO 0.062	Al ₂ O ₃ 1.00	SiO ₂ 1.279	RO 0.127	Al ₂ O ₃ 1.00	SiO ₂ 1.368
Total linear shrinkage						
at cone 14	10.47				9.65	
Deformation tempera-						
ture cone 33					32 ¹ / ₂	

Hocking and Perry Counties.—In the vicinity of Logan in Hocking and near Maxville in Perry County, the Sciotoville member is somewhat persistent in an area of a few square miles but in this flint clay is found only in isolated pockets. Upon these, however, brick works were established at Logan in 1874 and operated for refractory ware until 1890. Flint clay was also shipped from this district to Columbus for the manufacture of similar products. In this small field the average thickness of good flint clay is about two feet and the maximum measurement not more than four feet. The flint clay is often underlain by several feet of semiflint or “pink eye” of poor quality. Under present conditions these deposits do not warrant the establishment of plants and at best they could support but a small industry. The flint clay is generally of fair quality as shown in Table II, a representative test:

TABLE II

CHEMICAL COMPOSITION			
	Per cent		Per cent
Loss at 105°C	1.15	P ₂ O ₅	0.02
Ignition loss	10.53	Na ₂ O	trace
SiO ₂	52.58	K ₂ O	0.66
Al ₂ O ₃	30.45	MnO	.02
Fe ₂ O ₃	1.91	S	.02
CaO	0.26	Total	.15
MgO	.19	Inorganic C	.02
TiO ₂	1.94		
Oxide ratio	RO 0.094	Al ₂ O ₃ 1.00	SiO ₂ 1.791
Total linear shrinkage			
at cone 14	6.93		
Deformation temperature	cone 31½		

Lower Kittanning Clay

The Lower Kittanning clay, found just below the Lower Kittanning or No. 5 coal, is very persistent across the State as it extends with few wants from Lawrence County on the south to Columbiana County on the east. The position of the clay with reference to other well known members is, on the average, about twenty-two feet above the Vanport limestone and nearly thirty-five feet below the Middle Kittanning or No. 6 coal. The clay ranges in thickness from two to twenty feet and the overlying coal from a mere soot streak to six feet.

In most of the Ohio field only plastic clay is found on the Lower Kittanning horizon but in local areas flint clay is also present in small or large quantities. The largest and really the only important field of flint clay on this horizon in Ohio is in Sandy, Lawrence, Dover, and Franklin Townships in northern Tuscarawas County and in Rose Township in western Carroll County, the combined area of which is about fifty square miles. Owing to the position of the member high up on the hills and to the many wants, the actual area of flint clay is not in excess of ten square miles. Further, a part of this has been exhausted by mining. In this field the flint clay is bedded within plastic clay. In ascending order the succession is, on the average, 3 to 5 feet of plastic clay, 3 to 4 feet of flint clay, 3 to 5 feet plastic clay and 2 to 3 feet Lower Kittanning coal. The flint clay varies from 1 to 10 feet in thickness and is somewhat patchy in development. Of the plastic clays the one below the flint clay has the best properties and is the one used most largely for bonding purposes.

The flint clay in the Strasburg field was first used for refractory products in 1865 when a small plant was built by David Miller and Company at Dover. Other plants were then gradually erected so that at present eight works are in active operation in the district.

The largest supply of flint clay of good quality in Ohio is present in this

area. At that the total combined areas of undeveloped material appears to be not more than seven square miles, which is sufficient to take care of the needs of the present plants for some forty years and to provide for probably an equal number of new ones. Under such conditions, however, the field would be nearing exhaustion in fifty years or less.

The character of the flint clay in the Strasburg field is shown by the tests given in Table III.

TABLE III
CHEMICAL ANALYSIS

	Per cent	Per cent		Per cent	Per cent
Loss at 105°C	2.15	1.85	P ₂ O ₅	0.03	0.19
Ignition loss	11.29	11.78	Na ₂ O	.00	.04
SiO ₂	52.31	51.13	K ₂ O	.34	.05
Al ₂ O ₃	29.52	30.44	MnO	trace	trace
Fe ₂ O ₃	2.85	2.00	S	0.84	0.95
CaO	0.25	0.38	Total C	.26	.22
MgO	.06	.64	Inorganic C	.03	.01
TiO ₂	1.45	1.80			
Oxide ratio RO 0.109	Al ₂ O ₃ 1.00	SiO ₂ 1.822	RO 0.096	Al ₂ O ₃ 1.00	SiO ₂ 1.745
Total linear shrinkage,					
cone 14	7.01			9.23	
Deformation tempera-					
ture, cone 32 ¹ / ₂				32 ¹ / ₂	

Oak Hill Clay

The Oak Hill clay holds distinctive features from northern Lawrence to southern Coshocton Counties and may be identified in an impoverished condition in Stark and Columbiana Counties. It is found in the interval between the Lower Kittanning and the Middle Kittanning coals but in most places it lies much nearer the former than the latter. Although the field is large the clay occupies only a small part of this for it was deposited in isolated basins some of which are small in extent and widely spaced. Further, in most of the field the clay is impure, being so contaminated with iron oxides and calcareous matter that it falls below the class of high heat duty refractory materials. It holds the best properties and the best mining conditions in Jackson County and especially in a small area of a few square miles near Oak Hill. In this district the Oak Hill clay lies directly above the Lower Kittanning coal so that flint clay, plastic clay, and coal may all be taken from the same entry. Northward from this place shale varying from five to twenty feet in thickness intervenes between the coal and the clay which means that the beds would have to be mined separately.

The average thickness of the Oak Hill member is about three feet of which nearly one-half is flint clay of good quality and the other half plastic or semiflint clay with inferior properties. The maximum thickness of the flint clay is about three feet and that for the entire member ten feet.

The Oak Hill clay first attracted attention in 1873 when plants were built by the Aetna Fire Brick Company and by the Oak Hill Fire Brick Company. At present it is the main raw material used in four plants and is employed to a small extent in two more.

The quantity of Oak Hill clay in this small field yet available and with conditions favorable for drift mining is only ample to take care of the needs of the present plants. New operations are not justified. In the central and northern parts of the county where the clay lies several feet above the Lower Kittanning coal, the cost of mining would be prohibitive under the present status of the industry. In the remainder of the field in Ohio, that is, in Vinton, Hocking, Perry, Muskingum, Coshocton, and Columbiana Counties, the Oak Hill clay is too impure for high grade refractory products.

The quality of the Oak Hill clay in Jackson County is shown by the tests given in Table IV.

TABLE IV
CHEMICAL ANALYSIS

	Per cent	Per cent		Per cent	Per cent
Loss at 105°C	2.47	2.05	P ₂ O ₅	0.11	0.24
Ignition loss	10.72	11.96	Na ₂ O	.10	.34
SiO ₂	53.73	50.13	K ₂ O	.17	.14
Al ₂ O ₃	29.63	32.00	MnO	.01	trace
Fe ₂ O ₃	1.76	1.16	S	.09	0.06
CaO	0.21	0.14	Total C	.22	.11
MgO	.32	.08	Inorganic C	.20	.06
TiO ₂	1.10	1.75			
Oxide ratio RO 0.081	Al ₂ O ₃ 1.00	SiO ₂ 1.854	RO 0.055	Al ₂ O ₃ 1.00	SiO ₂ 1.629
Total linear shrinkage,					
cone 15	5.34			7.45	
Deformation tempera-					
ture, cone 32				32	

Lower Freeport Clay

The Lower Freeport clay adds but little to the ceramic resources of Ohio as, in a broad sense, the bed lacks continuity in the greater part of the field and as the material with few exceptions fails to meet the requirements for the manufacture of high heat duty refractory ware. It is of most value in a small area near Moxahala in Perry County where the member yields a flint clay of fair quality. The usual position of the Lower Freeport clay is about midway in the interval between the Middle Kittanning and Upper Freeport coals which are the best benches for reference and which are separated by about ninety feet of strata. More specifically, the Lower Freeport clay lies below the Lower Freeport limestone or where this is absent below the Lower Freeport coal. The common argillaceous material on the Lower Freeport horizon is plastic clay in which, locally, lenses and irregular masses of flint clay are interbedded. Such deposits

are uncertain in extent and generally quite variable in quality. Near Moxahala such deposits are irregularly distributed in Sections 30, 24, 19, and 20, Pleasant Township, and Section 17, Bearfield Township. In this district the member is made up of flint or plastic clay or both and has a thickness ranging from three to twenty-five feet. Part of the material in most places, however, is of poor quality. The quantity of clay in this locality is sufficient to last a few plants for many years. The chief objection is the uncertainty of the deposits and the frequent contamination by ferruginous and calcareous matter. At present the field furnishes clay for two plants and may never provide for more than this number. The tests given in Table V were made on representative material used for clay products.

TABLE V
CHEMICAL ANALYSIS

	Per cent		Per cent
Loss at 105°C	1.65	P ₂ O ₅	0.02
Ignition loss	9.05	Na ₂ O	.19
SiO ₂	59.71	K ₂ O	1.20
Al ₂ O ₃	24.58	MnO	trace
Fe ₂ O ₃	2.26	S	0.39
CaO	0.33	Total C	.43
MgO	.14	Inorganic C	.13
TiO ₂	1.14		
Oxide ratio	RO 0.158	Al ₂ O ₃ 1.00	SiO ₂ 2.476
Total linear shrinkage, cone 14	6.24		
Deformation temperature, cone 31			

General Conclusions

1. In Ohio the fields of flint clay of high heat duty quality are not inexhaustible, but are comparatively small and well defined.
2. The prospect of finding other deposits under deeper covering is not encouraging, in fact, drilling so far has not revealed any worthy of development.
3. The present fields have been worked for nearly fifty years which has exhausted much of the best material and, in general, that most easily available.
4. The known deposits are ample to support the present plants during their lifetime of fifty years but are not capable of supplying many new works which are required to take care of the increased consumption from year to year.
5. At the end of fifty years at the present rate of depletion most of the productive fields in this State will be exhausted or nearing this condition.
6. If conservation of our high heat duty clays is to be practised it should begin now, we should not wait until the supply is practically gone. The high heat duty clays should be conserved for high heat duty purposes only.

GEOLOGY OF THE BARABOO GANISTER DEPOSITS¹

By W. O. HOTCHKISS

Introduction

The Baraboo district for many years has supplied large quantities of high grade ganister rock for the manufacture of silica brick. For a long period it has made Wisconsin the second state in rank in the production of this material. Pennsylvania has been first with two-thirds to three-fourths of the total used in the country, while Wisconsin has furnished approximately one-fifth. Quartzite is being produced for ganister purposes by the General Refractories Company, and the Wisconsin Granite Company, whose quarries are located at Ableman; the American Refractories Company, whose quarry is at Devils Lake; and the Harbison-Walker Refractories Company, whose quarry is south of North Freedom. Table I of production gives the tonnage and value of ganister produced by Pennsylvania, by Wisconsin, and the U. S. total for the years 1918-1921 inclusive, according to the reports of the U. S. Geological Survey.

TABLE I

		Pennsylvania	Wisconsin	U. S. total
1918	Short tons	858,374	276,424	1,297,874
	Value	\$1,142,202	\$303,760	\$1,688,334
1919	Short tons	573,244	102,817	783,504
	Value	\$ 718,317	\$116,996	\$ 974,326
1920	Short tons	761,750	182,680	1,095,390
	Value	\$1,125,195	\$216,609	\$1,582,255
1921	Short tons	277,110	76,620	404,650
	Value	\$ 359,936	\$ 90,254	\$ 522,185

The distribution of this quartzite in the Baraboo region is indicated on the accompanying map (Fig. 1). The quartzite forms high ridges surrounding a beautiful valley about twenty-four miles long and varying from two to six miles in width. The outcrops of this quartzite in this region are abundant and large so that the stripping problem in quarry operations is very minor.

Geology

The geology of the Baraboo quartzite has been best described by S. Weidman² and much of the descriptive matter has been taken from that report. Like practically all quartzite, this formation was deposited originally as sand on a shallow sea bottom. These original sand beds accumulated to a thickness of approximately a mile. Most of the beds were composed of very pure quartz sand with some few beds of less pure character which contained small amounts of clay. Toward the top of the

¹ Presented before Refractories Division, Pittsburgh Meeting, Feb., 1923.

² Wis. Geol. and Nat. Hist. Surv., *Bull.* 13 (1904).

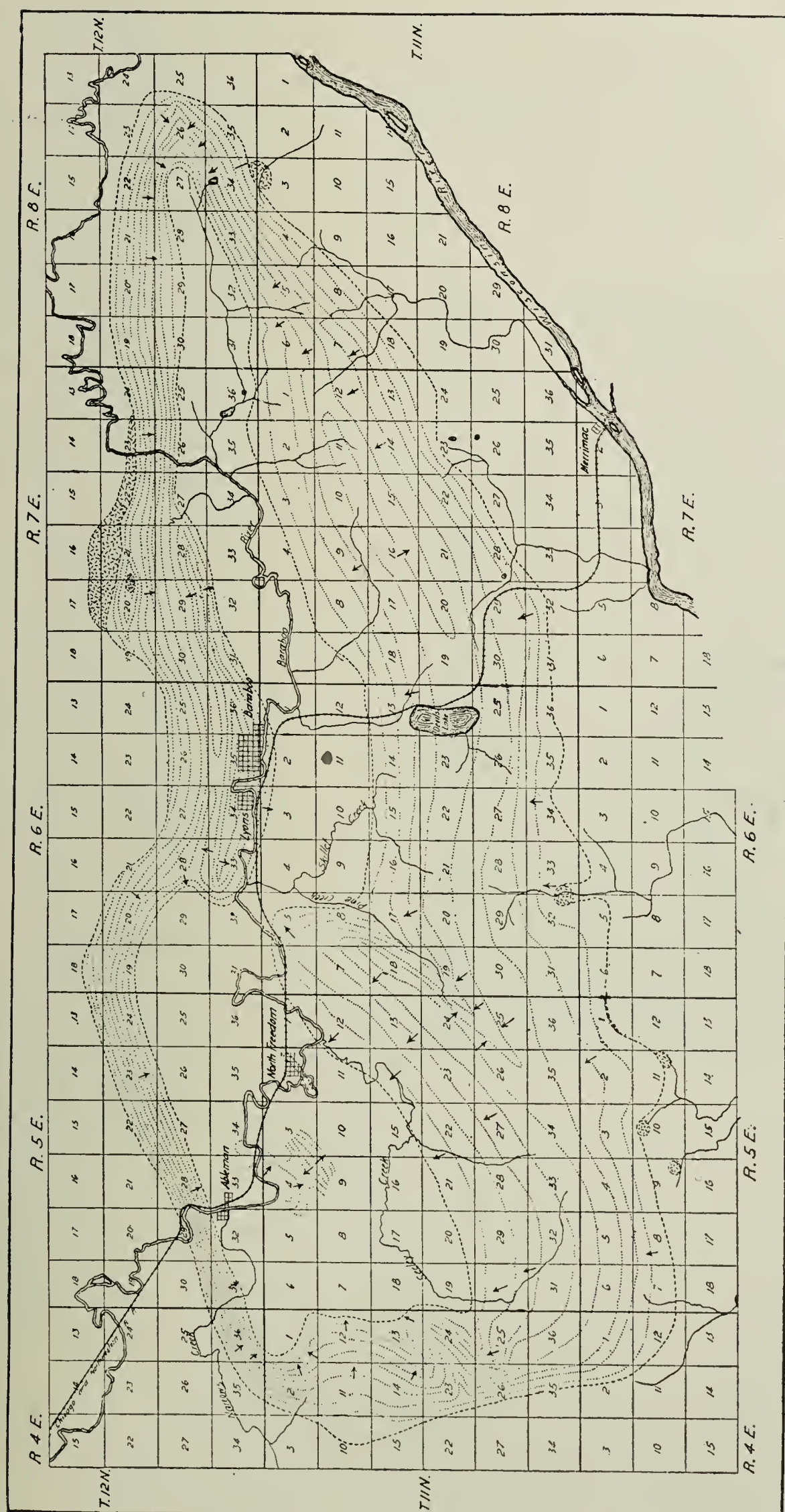


FIG. 1.—Map designed to show the structure of the Baraboo quartzite. The space between any two of the dotted lines represents an estimated thickness of 500 feet of quartzite. The direction of the dotted lines indicates the strike of the quartzite beds and that of the arrow heads the dip. The barred areas on the north and south sides of the quartzite represent outcrops of igneous rock, upon which the quartzite rests. From Weidman.

formation, and in a few places throughout its thickness, conglomerates are found which are composed to a very large extent of clear quartz pebbles. This original sand deposition was followed by a deposition of shale. This shale was a very fine-grained clayey material and accumulated to a thickness that is estimated at 500 to 1000 feet. At the present time none of this shale formation outcrops. It lies underneath the central portion of the valley together with the iron formation, the formation which was

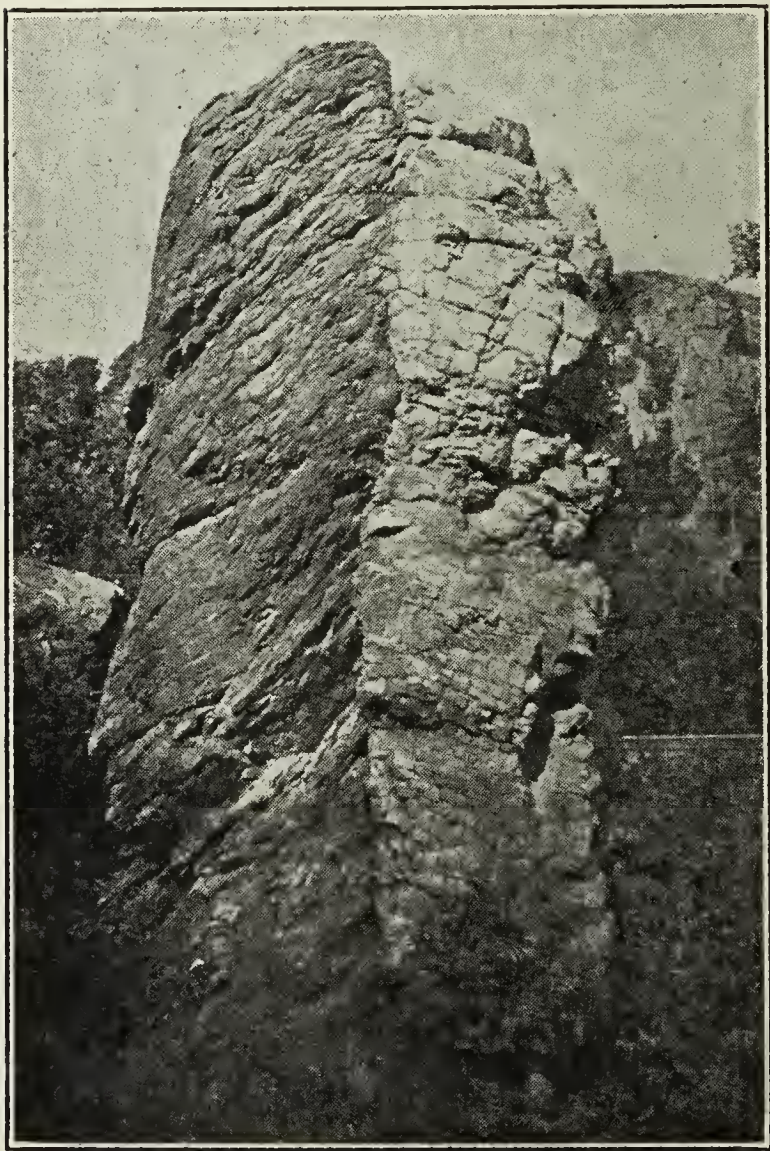


FIG. 2.—Van Hise rock. A mass of quartzite *in situ*, in the road through the Upper Narrows near Ableman. The bedding, which is nearly vertical, is indicated by the shading, while the secondary cleavage approaches horizontality.

deposited upon the shale. This upper portion of the Huronian series is now obscured by the Cambrian sandstones which form the surface rock in the central portion of the valley. After the deposition of this material there followed the cementation of the sand grains by the filling of the interstices with pure quartz. Most of this quartz cement was deposited in crystal continuity with the sand grains so as to completely fill the pore spaces. The thin section under the microscope at the present time shows an irregular mosaic of quartz grains. Some of them, by reason of the fact that the original sand grains had a thin cover of iron oxide, still show the outline of the original grains, but most of the grains are so lacking in iron oxide covering that it is impossible to tell exactly what is the original sand grain and what is the added silica cement.

After the cementing of the sands to quartzite the beds which now compose the Baraboo ranges were upheaved and folded into their present attitude. If you take a tablet $\frac{1}{2}$ inch thick and fold one edge of it up vertically you will note that the upper sheets glide over the lower ones and readjust themselves to the new position. In this great mass of quartzite a mile thick this readjustment between the beds had to take place.

The beds containing the greatest amount of clay were naturally the weakest and consequently were the ones which yielded during the folding. We

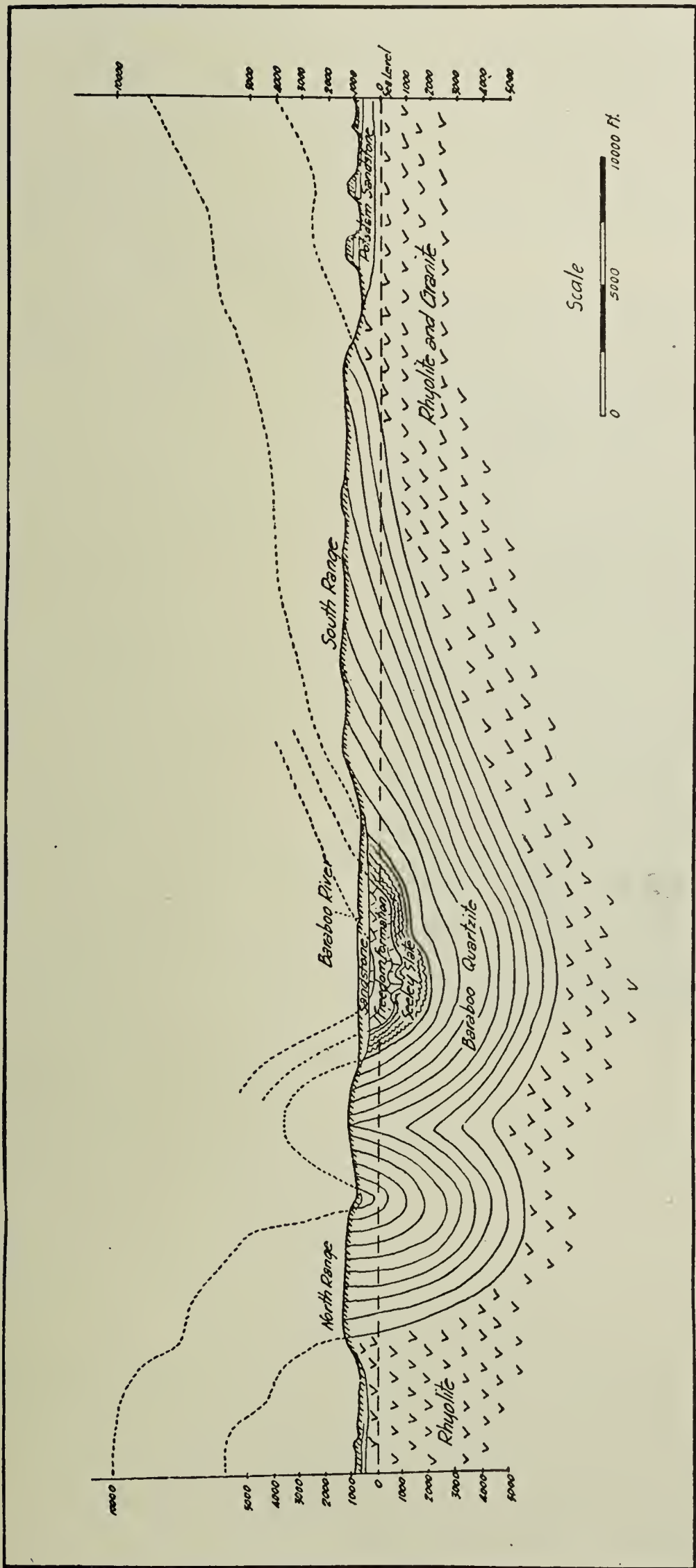


FIG. 3.—Generalized cross-section extending north and south across the Baraboo district. The horizontal and vertical scales are the same. The Baraboo quartzite rests unconformably upon the basement of igneous rock, consisting of rhyolite, granite, and diorite. The continuous lines represent the synclinal folds of the quartzite, slate, and freedom formation, upon which rests unconformably the overlying Potsdam sandstone. The dotted lines indicate the probable position of the quartzite, slate, and freedom formation above the present surface before they were eroded. From Weidman.

have in Fig. 2 (the Van Hise rock) the pure bed of quartzite to the right (originally the top bed of the two) and the somewhat more clayey quartzite to the left. In this latter bed is evident well-developed schistosity, even though the original clay content was probably less than 5%.

The folding to which this quartzite formation has been subjected is illustrated by the cross-section (Fig. 3), which was taken from Mr. Weidman's report. From this it will be noted that the beds on the South Range,

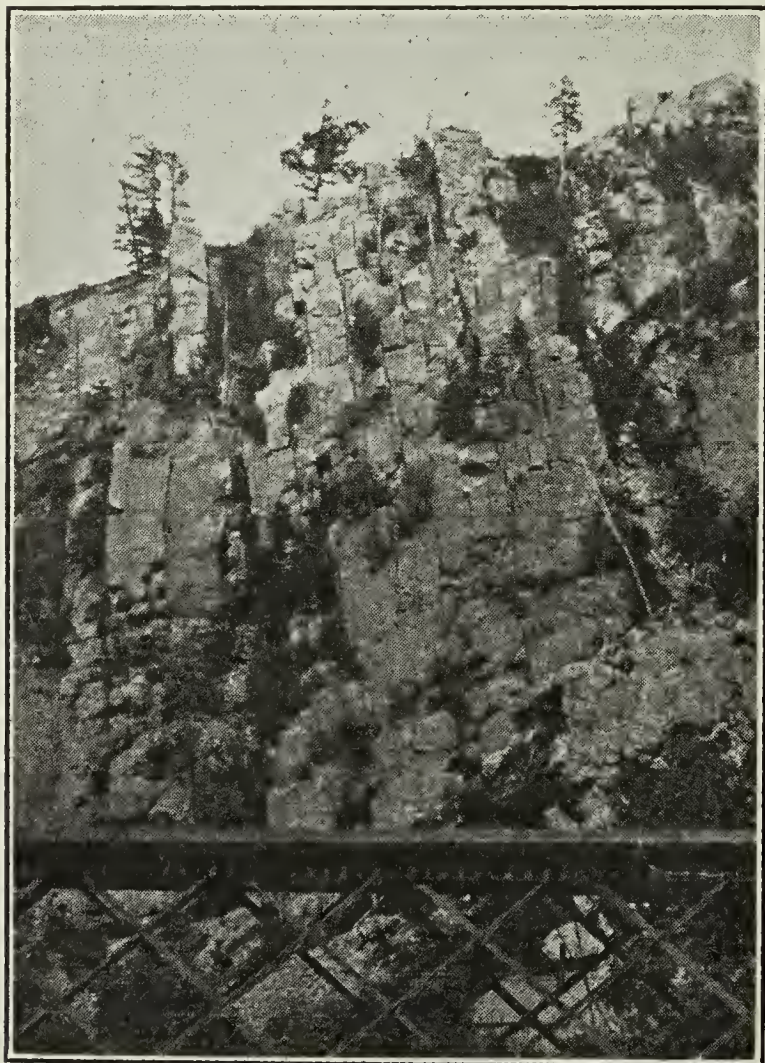


FIG. 4.—The east bluff of the Upper Narrows of the Baraboo at Ableman. Shows the south dip of the beds of quartzite. (After Salisbury and Atwood in Wis. Geol. and Nat. Hist. Survey, *Bull.* 5.)

which are those quarried at Devils Lake and to the south of North Freedom, have a rather gentle northward dip varying from 15° to 35° or 40° , while in the North Range the beds are approximately vertical. This vertical dip is also shown in Fig. 4.¹ This photograph was taken to show the east face in the gorge at Ableman. Similar cliffs occur on the west side of this gorge, and also at Narrows Creek, Narrows, about two miles west of Ableman, and in the Lower Narrows of the Baraboo River about 6 miles somewhat east of Baraboo.

Physical Characteristics

The original sand grains, of which the quartzite is composed, are well rounded and subangular in outline and are of medium size. Probably the whole of these grains, if they could be separated, would go through a

¹ Taken from Wis. Geol. and Nat. Hist. Surv., *Bull.* 5.

Chemical Composition and Variation

The great mass of this quartzite is strikingly pure in silica. At the base there are conglomerates and shale beds which make the quartzite impure for a thickness of a very few feet, and the transition beds of Seeley slate which overlie it are a mixture of quartz and slate, but these are a relatively few feet in thickness. Another notable peculiarity of this formation is the complete absence of alkalis. This lack of alkali also persists into the Seeley slate overlying, of which Table II is a very careful analysis made by Dr. Victor Lenher of the University of Wisconsin and published in Weidman's *Bulletin*:

TABLE II
ANALYSIS OF SEELEY SLATE

	Per cent		Per cent
SiO ₂	62.03	K ₂ O.....	trace
Al ₂ O ₃	29.34	H ₂ O (at 110°).....	0.01
Fe ₂ O ₃	trace	H ₂ O (at red heat).....	2.24
FeO.....	5.09	TiO ₂	none
MnO.....	none	P ₂ O ₅	0.08
MgO.....	0.29	Cr ₂ O ₃	none
CaO.....	.16	CO ₂	none
Na ₂ O.....	trace	C.....	none
		S.....	0.10
Total.....			99.40

From this it appears that this slate is almost wholly made up of silica, alumina and ferrous oxide.

The following analyses of the Baraboo quartzite were also made by the same analyst in 1911. In all of these analyses tests were made for alkalis and none found. In the note on these analyses the general stratigraphic position of the samples of which the analyses were made is given. These indicate that practically the whole of this formation is sufficiently pure in silica to be available for ganister. The samples that were collected for analysis were carefully taken to give very representative analyses of the localities selected. For this purpose a very considerable number of chips were taken from different parts of the outcrop or of the quarry and in Table III the number of chips is indicated.

Supply Extensive

From this information it is evident that there is a limitless supply of this material in the Baraboo ranges. As a matter of fact, the total amount of quartzite in this formation is measured by hundreds of cubic miles, and even though much of it would be unavailable because of depth, the quantities that can be quarried easily are so vast as to be limitless no matter what calls may be made upon them.

TABLE III

	Loss on ignition, per cent	SiO ₂	Fe ₂ O ₃		Al ₂ O ₃	CaO		MgO
1	0.28	97.99	0.70	Fe = 0.49	0.99	0.01		0.03
2	.54	97.95	.70	Fe = .49	.79	.01		.01
3	.40	98.84	.33	Fe = .23	.41	.00	Less than 0.01	.02
4	.59	97.98	.90	Fe = .63	.50	.01		.02
5	.70	98.12	.36	Fe = .25	.79	.02		.01
6	.45	98.11	.41	Fe = .29	1.00	.02		.01
7	.56	96.62	.79	Fe = .55	2.00	.00	Less than 0.01	.03
8	.46	98.22	.23	Fe = .16	1.08	.00	Less than 0.01	.01
9	.62	98.93	.17	Fe = .12	1.27	.00	Less than 0.01	.01
10	.60	98.59	.23	Fe = .16	0.53	.03		.02
11	.44	98.81	.08	Fe = .06	.67			
(Includes CaO, MgO)								
12	.33	99.04	.28	Fe = .20	.35			
13	.51	97.17	.97	Fe = .68	1.35			
14	.52	98.51	.16	Fe = .11	0.81			

1. American Refractories Co., Devils Lake. Taken from 4 cars, about 45 chips from each car. 180 chips. (1911)—Quarry 500–1000 feet from top of formation.

2. From ledge near center of quarry about 60–150 feet from railroad track at American Refractories Co., Devils Lake, Wis. 1911, 20 chips.

3. Specimens from Vilas Property, Devils Lake. 1911, 110 chips.

4. Samples from Claude Property, N. W. Corner Devils Lake. 1911, 73 chips. Within 500 feet of top of formation.

5. Mr. Kirk's Property, Devils Lake. 1911, about 50 chips. About the middle of the formation.

6. Specimens from Dyke Ringling's Property, Devils Lake. 1911, 45 chips. About the middle of the formation.

7. Sample from Hopkin's Quarry, Devils Lake, Wis. 1911, 65 chips. About the middle of the formation.

8. LeRue's Quarry at Ableman, Wis. Rock ready for shipment. Harbison-Walker Co. From 1 car and pile. 1911, 90 chips. About 1500–2000 feet from top of the formation.

9. Sample American Refractories Co. Hultz Site, 1 mile south of Ableman, Wis. 1911, 55 chips. Probably in upper part of formation.

10. Rattlesnake Den Site, Erswell Quarry Site, 1 mile south of LeRue, Wis. 1911, 65 chips. Near top of formation.

11. Sample from Rick Property, 1–1½ miles southeast of Ableman, Wis. 1911, 63 chips. Probably near top of formation.

12. Fleming Property, 1 mile south of Ableman, Wis. 1911, 43 chips. From upper part of formation.

13. Sample from Quarry of Wisconsin Granite Co., Ableman, Wis. Best hard rock. 1911, 58 chips. Near middle of formation.

14. Sample from the Narrows Creek, Narrows, 2 miles west of Ableman, Wis. 1911, 109 chips.

REFRACTORY CLAYS OF THE ALBERHILL, CALIFORNIA DE- POSITS

By B. M. BURCHFIELD

ABSTRACT

A brief description of the clay deposits at Alberhill, Calif., is presented. The more important refractory clays of these deposits are described. Chemical analyses are given, along with shrinkage, water of plasticity, and fusion point data.

Introduction

The Alberhill, California clay deposits are situated in western Riverside County about seventy miles southeast of Los Angeles in the center of a region that is noted for its large quantities of many different varieties of clays. This region, for the most part, lies in the Tamescal Valley, which was in Tertiary times an arm of the sea which extended northward into what is now San Bernardino County.¹

The largest clay mine of this region is that of the Alberhill Coal and Clay Company at their famous "Mountain of Clay." This deposit was opened up several years ago as a coal mine. The coal, however, was of rather poor quality and limited as to quantity. Consequently it soon became of secondary importance, for enormous quantities of excellent clays were found both above and below the coal, and these proved to be of far greater value and importance than the coal. At the present time there is practically no coal mined here, but about 90% of the high grade clays used in southern California come from this deposit.

This single body of clay has been pronounced unique by many men who are familiar with clay deposits all over the world, because it contains such a large number of totally different clays in so small an area. Several years of development has opened up a pit in which there is exposed a face of clay approximately 2000 feet long, and varying from fifty to a hundred feet in thickness. There are a great number of slips and faults in this deposit, but the following cross-section is fairly representative:

No. of feet	Kind of strata	No. of feet	Kind of strata
3	Soil	4	Bone Clay No. W-105
20	Yellow Top Clay	4	Clay between Bone and Blue Clays
6	Yellow M. T. Clay	12	Select West Blue Clay
34	M. T. Clay	8	W. T. Blue Clay
6	Coal		Shale

Yellow Top Clay

This yellow top clay is not refractory, but it is used by some manufacturers to temper certain refractory mixes where hardness and density are desirable and very high refractory properties are unnecessary. It

¹ Fletcher Hamilton, "The Clay Industry in California," Calif. State Mining Bureau, *Prelim. Report*, No. 7, Jan., 1920.

is not a true clay, but is decomposed granite. It is quite yellow in color. At cone 12 it is nearly black, and shows some evidence of overburning. This material makes excellent red face brick when mixed with other clays.

PHYSICAL PROPERTIES

Linear drying shrinkage	7 %
Linear burning shrinkage	5.4% of dry length, at cone 12
Water of Plasticity	31.5%
Fusion Point	Cone 14

CHEMICAL ANALYSIS

	Per cent		Per cent
Ignition Loss	10.06	Lime	2.00
Silica	62.12	Magnesia	0.68
Alumina	19.22	Alkalies	1.22
Ferric Oxide	5.04		
Total			100.34

Yellow M. T. Clay

This clay is plastic and works well. It contains some free silica. It is quite yellow in color. It burns to a beautiful buff at cone 12, and is quite hard. No signs of overburning are apparent at this temperature.

PHYSICAL PROPERTIES

Linear drying shrinkage	9%
Linear burning shrinkage	4.4% of dry length, at cone 12
Water of Plasticity	32.4%
Fusion Point	Cone 28

CHEMICAL ANALYSIS

	Per cent		Per cent
Ignition Loss	10.08	Lime	0.52
Silica	58.06	Magnesia	.31
Alumina	27.48	Alkalies	1.12
Ferric Oxide	2.52		
Total			100.09

M. T. Clay

This stratum of clay is the main one of the deposit. It is a white, siliceous, plastic clay. It contains a fairly large quantity of free silica which occurs for the most part in well-defined streaks of very sandy clay. This sand can readily be sorted out if extra smooth clay is desired. But for all general purposes this is not done, for the percentage of sand throughout the entire stratum is not excessive. This clay burns to a light cream color at cone 12.

PHYSICAL PROPERTIES

Linear drying shrinkage	8 %
Linear burning shrinkage	2.2% of dry length, at cone 12
Water of Plasticity	24.3%
Fusion Point	Cone 29

CHEMICAL ANALYSIS (BURNED)

	Per cent		Per cent
Ignition Loss	0.16	Lime	0.42
Silica	73.66	Magnesia	Trace
Alumina	22.86	Alkalies	0.64
Ferric Oxide	2.36		
Total			100.10

Bone Clay No. W-105

This is a white clay, slightly spotted with small black particles of iron oxide, and in some cases pyrites. It is not at all plastic. When calcined, it is quite hard but it breaks up easily, and makes excellent grog for high grade fire brick. It burns almost pure white.

PHYSICAL PROPERTIES

Linear drying shrinkage	3 %
Linear burning shrinkage	9.2% of dry length, at cone 12
Water of Plasticity	23.4%
Fusion Point	Above cone 33

CHEMICAL ANALYSIS (BURNED)

	Per cent		Per cent
Ignition Loss	0.26	Lime	Trace
Silica	54.85	Magnesia	Trace
Alumina	43.43	Alkalies	0.86
Ferric Oxide	0.72		
Total			100.12

Clay between Bone Clay and Blue Clay

In the raw state the general appearance of this clay is very similar to that of the above mentioned bone clay No. W-105. This clay, however, contains some very finely divided silica which the bone clay does not have. This clay also contains a small amount of iron scattered all through it. When burned to about cone 12 this iron gives the clay a brown speckled appearance.

PHYSICAL PROPERTIES

Linear drying shrinkage	5 %
Linear burning shrinkage	7.3% of dry length, at cone 12
Water of Plasticity	24.2%
Fusion Point	About cone 33

CHEMICAL ANALYSIS

	Per cent		Per cent
Ignition Loss	10.72	Lime	Trace
Silica	61.20	Magnesia	0.05
Alumina	27.29	Alkalies	Trace
Ferric Oxide	0.77		
Total			100.03

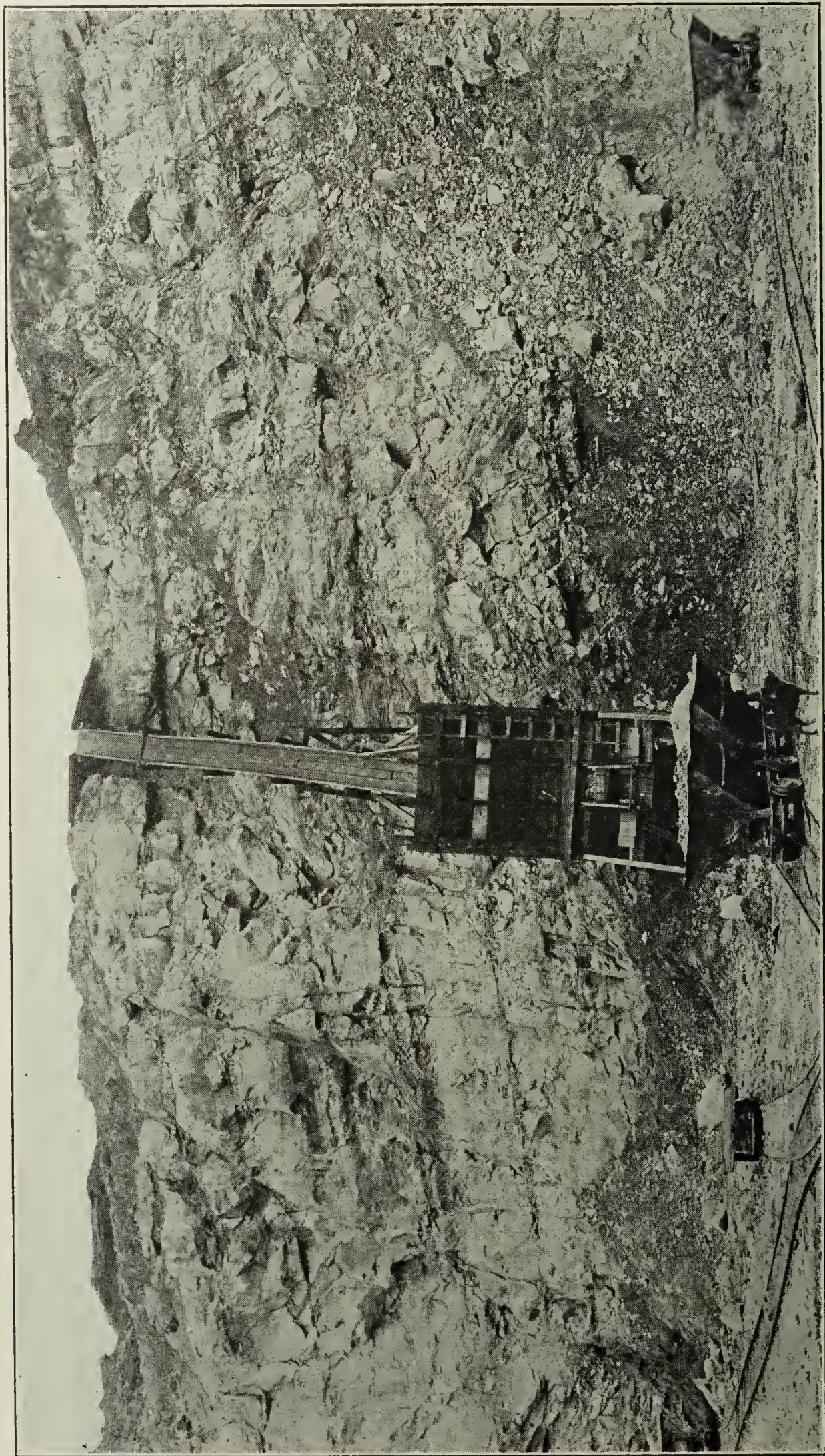


FIG. 1.—Rear wall, main pit showing fire clay over lignite.

Select West Blue Clay

This clay is very smooth and plastic. It is quite blue in color and slightly mottled with white. There is such a demand for this clay among the manufacturers of face brick, terra cotta, chemical stoneware, pottery, etc., that it is not used in fire brick to any great extent.

This clay dries extremely well. When burned it is very strong and hard. It is cream colored at cone 12.

PHYSICAL PROPERTIES

Linear drying shrinkage	5 %
Linear burning shrinkage	6.3% of dry length, at cone 12
Water of Plasticity	31.1%
Fusion Point	About Cone 32

W. T. Blue Clay

In regard to plasticity and general working qualities this clay is quite similar to Select West Blue Clay. Its color, however, has a decided green cast that is not apparent in that of the Select clay.

This clay burns hard and strong. At cone 5 it is light red in color. At cone 12 it is somewhat darker and contains fine black iron spots. This clay is excellent material for hollow building tile, roofing tile, etc.

PHYSICAL PROPERTIES

Linear drying shrinkage	6 %
Linear burning shrinkage	5.3% of dry length, at cone 12
Water of Plasticity	30.2%
Fusion Point	Cone 26-27

As this deposit continues to the north it rises gradually and its character changes. There is not so much clay on top of the coal. Underneath the coal the bone clays are replaced by about five feet of clay known as SH-4 clay. Underneath this the blue clays occur about the same as they do beneath the bone clays.

SH-4 Clay

This is a smooth ball clay of very high quality. It is used to a great extent in pottery of various kinds, and is suitable for use in china and porcelain mixes. A very high grade of refractories is made from this clay. It is dark gray-blue in color, and is extremely plastic and somewhat sticky.

When burned it is very hard and dense. It is white in color, and some samples have a light blue-gray cast.

PHYSICAL PROPERTIES

Linear drying shrinkage	5 %
Linear burning shrinkage	16.8% of dry length, at cone 12
Linear burning shrinkage	17.9% of dry length, at cone 14
Water of Plasticity	31.7%
Fusion Point	Above cone 33

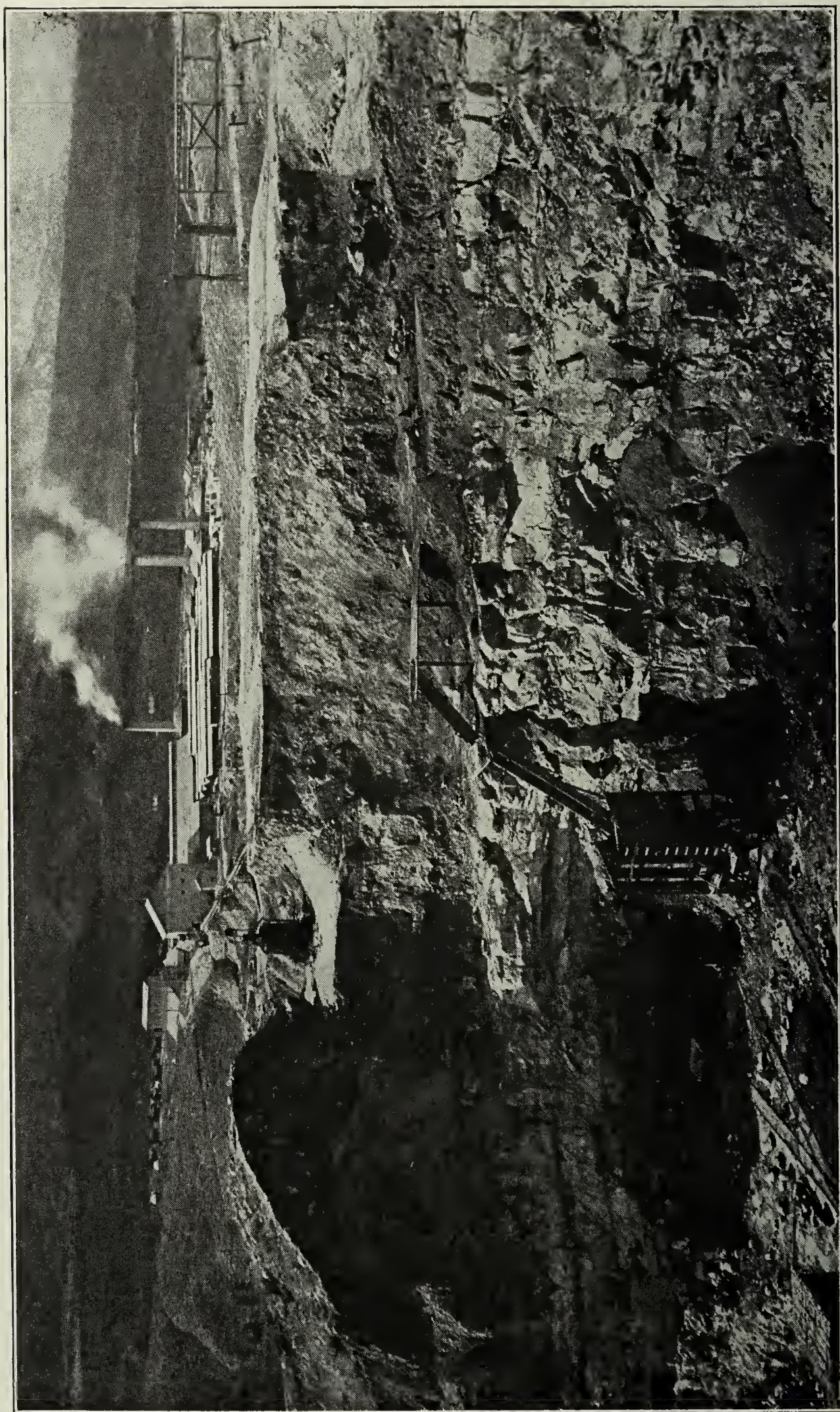


FIG. 2.

CHEMICAL ANALYSIS

	Per cent		Per cent
Ignition Loss	18.96	Lime	0.72
Silica	37.72	Magnesia	.05
Alumina	42.21	Alkalies	.09
Ferric Oxide	0.51		
Total			100.26

In addition to these clays just described there is a vein of bauxite about two feet thick which comes to the surface near the south side of the present open pit. Considerable silica, iron and fluxes are present in this bauxite at the outcropping, but it is probable that some of these impurities disappear deeper down in the deposit. It is nonplastic and quite refractory. It burns extremely hard. At cone 12 it is dark red in color, and has a total drying and burning shrinkage of 16%. Results of its chemical analysis are as follows:

CHEMICAL ANALYSIS

	Per cent		Per cent
Ignition Loss	15.32	Lime	0.62
Silica	38.96	Magnesia	.16
Alumina	35.76	Alkalies	1.02
Ferric Oxide	8.30		
Total			100.14

There are other good fire clays in this deposit, but these just described are the most important. Hill blue clay, which comes from another pit near the one just described, is a very plastic, highly refractory clay of excellent quality. But it, like some of the other clays, is used almost entirely in the face brick, terra cotta and other industries.

Sloan Clay

Another important clay deposit in this vicinity is that of the Los Angeles Pressed Brick Co. It is known as the Sloan Pit, and lies about a half mile southwest of the deposit just described. In this pit a face of clay is exposed which is over a hundred feet in length and approximately eighty feet in height. A representative cross-section is as follows:

No. of feet	Strata
40	Overburden and Yellow Top Clay
30	Sloan Clay
6	Sloan No. 5 Clay
4	Sloan Bone Clay. (Present level)
50	Red Clay

This yellow top clay is quite similar to that which is found at the Alberhill Coal and Clay Company deposit. There are a few veins of coarse sand in this top clay, however, which is used extensively in certain kinds of face brick.

This large body of clay is white and smooth and quite plastic. A few small veins of free silica are present, but these occur in well-defined layers. This clay is used extensively in face brick and terra cotta. It burns white.

PHYSICAL PROPERTIES

Linear drying shrinkage	8 %
Linear burning shrinkage	4.3% of dry length, at cone 12
Water of Plasticity	32.6%
Fusion Point	Cone 30

CHEMICAL ANALYSIS

	Per cent		Per cent
Ignition Loss	10.90	Lime	0.90
Silica	55.56	Magnesia	.20
Alumina	28.79	Alkalies	1.40
Ferric Oxide	1.77		
Total			99.52

Sloan No. 5 Clay

This is a very smooth, plastic ball clay, similar in all respects to the SH-4 clay just described. It is dark blue-gray in the bank, but is almost white when dry. It burns white and is extremely hard. This clay is used exclusively for highly aluminous fire-clay refractories.

PHYSICAL PROPERTIES

Linear drying shrinkage	5 %
Linear burning shrinkage	9.4% of dry length, at cone 5
Linear burning shrinkage	16.8% of dry length, at cone 12
Linear burning shrinkage	17.9% of dry length, at cone 14
Water of Plasticity	34.6%
Fusion Point	Above cone 33

CHEMICAL ANALYSIS

	Per cent		Per cent
Ignition Loss	15.72	Lime	Trace
Silica	41.48	Magnesia	Trace
Alumina	41.50	Alkalies	0.35
Ferric Oxide	0.80		
Total			99.85

Sloan Bone Clay

This clay is practically identically the same as the bone clay No. W-105 from the other deposit.

The red clay which underlies this clay is extremely plastic and easily worked. Very excellent hollow tile, roofing tile and red face brick are made from this clay.

Conclusion

It may be readily seen that this large variety of clays makes possible the manufacture of suitable refractories for nearly all purposes where clay refractories may be used. These clays are easily obtained in any reasonable amounts. Consequently the refractories industry in this region can be highly specialized. Each product can be made out of the clays best suited to withstand the conditions to which they may be subjected in actual use.

NOTE: The writer wishes to thank Jas. H. Hill, Pres., and Finlay Drummond, Vice Pres. and Gen. Mgr. of the Alberhill Coal and Clay Co., and J. E. Mills, Mine Supt. of the Los Angeles Pressed Brick Co. for valuable assistance in the preparation of this paper.

REFRATORIES LABORATORY
LOS ANGELES PRESSED BRICK CO.
ALBERHILL, CALIF.

REFRATORIES COLLOQUIUM—CONSUMERS' PROBLEMS

REFRACTORY REQUIREMENTS FOR OIL REFINING

BY ALAN G. WIKOFF

ABSTRACT

Aside from boiler settings and such minor uses as fullers earth revivifying furnaces and sludge acid recovery plants, the main use for refractories in oil refineries is in fire still settings. With the shell type stills which were almost exclusively used in the past, service conditions are not severe enough to require anything more refractory than the best quality No. 1 fire brick, but some of the tube type cracking stills recently introduced are much more severe in their refractory requirements.

While all oil refineries may be said to have a common objective—that of treating crude petroleum by fractional distillation or pyrolysis so as to obtain products for which there is a greater demand—the methods employed vary considerably with the type of crude treated, the size of the refinery, and indeed change from time to time within the same plant to meet fluctuations in market conditions. In general, however, the crudes are treated in direct-fired stills of either cylindrical shell or tube type to yield the primary fractions, some of which may be marketed directly, others cracked in fire stills, others refractionated in steam stills, purified by chemical treatment in agitators, and so on through an almost endless variety of processes. From all of these the important points at which refractories are required may be summarized as follows:

- | | |
|--------------------------|---------------------------------------|
| 1. Boiler plant | B. Tube type: |
| 2. Fire stills: | (1) Topping |
| A. Shell type: | (2) Cracking |
| (1) Crude or Topping | 3. Fullers earth revivifying furnaces |
| (2) Coking | 4. Sludge acid recovery |
| (3) Cracking or Pressure | |

Because of the large amounts of process steam required, the boiler plants in many refineries are of considerable magnitude but as they do not differ materially from plants in other industries, consideration of their problems belongs properly with the subject of refractory requirements for boiler settings in general. It may be noted in passing, however, that in one of the largest complete refineries in the country the most severe service conditions for refractories are found in the boiler house.

Before turning to the question of fire stills, items 3 and 4 may be dismissed with brief consideration because the application of these processes is limited to a comparatively small number of refineries. In the treatment of certain products, particularly lubricating stocks, clarification by means of fullers earth may be required and for the regeneration of the spent earth various types of furnaces are used, such as rotary kilns, wedge

mechanical roasters and specially designed furnaces in which the earth drops vertically through baffled passages or slides over a series of slopes in direct contact with the flame.

One of the steps in the purification of such products as gasoline is agitation with a small percentage of 66 Baumé sulphuric acid, the acid combining with certain organic compounds to form a sludge which is drawn off at the bottom. A number of processes have been devised for the recovery of this sludge. In several of these the chief ceramic requirements are acid-proof stoneware rather than refractories, but one system concentrates the acid by blowing through it hot gases which are the combustion products of an oil burner supplied with air under pressure. As the gases reach the acid at a temperature of about 1200°F, combustion chamber refractories are subjected to quite severe conditions.

The remaining classification, fire still settings, constitutes the major application of refractories in oil refineries. From the standpoint of settings, it is most convenient to divide fire stills into two groups, shell and tube, depending upon the design of the steel container in which the oil is heated. In 1919, according to the Census of Manufactures, the refineries of the country had 4394 fire stills and 1480 pressure stills or a total of 5874 stills requiring refractories in their settings. Because of variation in size and in method of building settings it is not possible to estimate from this figure the total amount of refractories in use.

Shell Type Fire Stills

As the name would indicate, shell type stills are cylindrical in shape with bumped ends. They are supported in a horizontal position over an open setting, one end of which usually serves as a fire box, although a few stills are side fired. Capacities are rated according to the number of barrels of oil which constitute a charge and the shell dimensions corresponding to some of the more usual sizes are as follows:

Capacity—bbl.....	150	300	600	1000
Dimensions—ft.....	8 x 20	9 x 30	11 x 40	14 x 40

Although it cannot be taken as truly representative, for there is no design which is universally accepted in all details, the following description of a 1000-bbl., 14 x 40 feet crude still will give an idea of the way in which settings are built for shell stills. The shell, built up of heavy steel plate (the bottom sheets being 1/2-inch best quality fire-box steel), is supported on each side by eight cast-iron or pressed-steel lugs, which rest upon 7-foot steel columns set on concrete foundations 6 feet 6 inches high, so that the lugs and center line of the shell are 13 feet 6 inches above the still foundation. Viewed from the end the inside width of the setting is 9 feet 6 inches at the bottom tapering outward as it rises until it is the full

width of shell at the lugs, where the setting ends. Above this point the shell is covered with blocks of heat-insulating material such as Sil-O-Cel, finished with a waterproof cement. Gutters on each side prevent rain from entering setting or combustion chamber. The heads of the still drums are insulated in a similar manner.

Front and rear walls are built up to conform to the curved underside of the shell, with 9 inches of fire brick toward the inside, then four inches of Sil-O-Cel, with the outside red brick or concrete. Two fire-brick lined openings in the front wall provide for firing and ash removal. From these a grate extends seven feet back to the front bridge wall, four feet high and faced with fire brick. About three feet from the rear wall is a second bridge wall which extends to within eighteen inches of the still bottom, so that its upper edge is curved. The space between the two bridge walls is filled with cinders so that the products of combustion are forced up against the bottom of the still and must pass through the 18-inch space between the still and the top of the rear bridge wall before passing to the 2-foot vertical flue immediately behind and then to the three-foot horizontal flue in the rear wall leading to the stack. The side walls are nine-inch fire brick backed with four-inch Sil-O-Cel. Where the cinder fill is used, the fire brick extends for a foot or so below the cinder surface, the lower portion protected by the cinders being of common brick. In brief, wherever exposed to combustion gases, the interior of the setting is faced with fire brick.

Settings of this type need nothing more refractory than No. 1 fire brick, the general requirements being medium grade with good wearing qualities rather than ability to resist high temperatures. The temperatures encountered depend upon the method of firing and upon the process being carried out in the still.

Fuel may be either oil or coal. Some refineries in the mid-continent field burn fuel oil which is unmarketable because of the high content of bottom settlings. The mineral matter in these bottom settlings may often cause slag trouble. Coal is usually fired by hand although stokers are used in some of the larger refineries. In the latter case, best quality No. 1 fire brick are required in the combustion zone.

Shell stills may be used for topping or skimming crudes, that is, removing simply gasoline and other light fractions, the entire residue being sold as fuel oil or cracked to obtain further quantities of gasoline; treating crudes to obtain a number of fractions; running certain types of crudes to dryness, until a thick layer of coke is formed on the still bottom; cracking heavy fractions by heating under pressure.

For topping and treating crudes, the stills may be operated intermittently and individually, or the continuous process may be used. In the latter, end-fired stills are cast in batteries of four to twelve, six being common,

and operated in groups of four, five, or more, each still in the group being maintained at a higher temperature than the one preceding it. Crude enters at the low temperature end and passes through each still in turn, heavier and heavier fractions being removed, until it finally leaves the last still as residuum. With this arrangement, a run may last for 10 to 15 days, or until the last still requires cleaning out, so that the setting suffers less from expansion and contraction than during batch operations for topping. The maximum oil temperature is in the neighborhood of 500° to 600°F.

In coking stills, the final temperature inside the still is about 890°F and a run averages forty hours. Cracking or pressure stills of the Burton type may hold 200 barrels or more and operate at 650° to 850°F under a pressure of four to five atmospheres, the furnace temperature being from 1350° to 1600°F. This is probably the most severe service in shell still work, best quality No. 1 fire brick being required.

As has been indicated, the temperature conditions for shell still setting are not extremely severe, and such refractory troubles as have been experienced are due as a rule either to spalling resulting from short runs which cause sudden temperature changes, or to improper laying of the brick. While in large refineries the settings may be constructed under engineering supervision, small refineries often depend upon local contractors who have had little or no experience in laying refractories. The result is that the manufacturers are frequently blamed for failures which are really due to improper use of the product.

Tube Stills

To meet the demand for fuel oil in California, there have developed a number of types of tube stills which permit continuous and economical removal of the lighter fractions from the crude, leaving the desired fuel oil. These types have been described and illustrated so completely in a 160-page report by J. M. Wadsworth¹ that it is unnecessary to go into detail here. In a Bell type plant, at Avon, California, crude is heated to 435–450°F by passing continuously through three rows of thirty-six 4-inch wrought iron pipes twenty feet long set across a furnace heated by oil burners in fire-brick lined Dutch ovens.

In the application of the tube still principle to the cracking of heavy fractions, extremely severe service conditions are encountered. In one cracking process of this type, combustion chamber temperatures as high as 2800°F are required in order to maintain the oil circulating in the tubes at 820°F. A coating of high temperature cement over No. 1 fire brick has

¹ J. M. Wadsworth, "Removal of the Lighter Hydrocarbons from Petroleum by Continuous Distillation," Bureau of Mines, *Bull.* 162.

been found effective in eliminating refractory trouble. Since plants of this type can obtain about 30% of gasoline from ordinary fuel oil and still leave a residue marketable as fuel oil, they seem particularly capable of helping the refiners meet the ever-increasing demand for gasoline. While it is impossible to make any prediction in view of the involved patent situation, it is evident that extensive use of tube type cracking plants would greatly increase the demand for high grade refractories by the oil refining industry.

The writer regrets that it has not been possible to give more definite data in this brief review but the fact is that in the past no one in the industry has given much attention to refractories and data are accordingly unavailable. Should the demand for increased gasoline production be met by the use of tube type cracking plants it seems quite probable that the oil refiner will require more attention from the refractory manufacturers.

NEW YORK CITY

METALLURGICAL REQUIREMENTS FOR REFRATORIES IN THE ELECTROTHERMIC METALLURGY OF ZINC¹

BY B. M. O'HARRA

ABSTRACT

Refractory brick for lining electrothermic dry distillation furnaces must have a melting point of not less than 1600°C, must retain their strength at temperatures of 1400–1500°C, must be non-porous, and of uniform size. For lining electrothermic smelting furnaces, in which a liquid slag is produced, they must in addition to having these qualities be resistant to the corrosive action of highly heated slags which may be either strongly acid or strongly basic. The condensers are similar for both types of furnace. The brick for lining them need not have a high melting point but must be dense and of uniform size and must be very low in free iron oxide to withstand the disintegrating effect of carbon monoxide in the cooler portion of the condenser.

Refractory materials used in electrothermic processes for the treatment of zinc ores may be divided for the purpose of discussion into two classes: Those used in the smelting, or distillation furnace; and those used in the condenser. The preliminary roasting of the ores for treatment by an electrothermic method is the same as for the ordinary retort process, and is done in the same types of furnace so that no discussion of refractories for roasting furnaces is necessary here.

Electric Smelting

Electrothermic processes belong to two types: Electrothermic dry distillation, and electric smelting proper. Electrothermic dry distillation is similar in principle to the retort process, in which the ore is mixed with

¹ Presented before the Refractories Division, Pittsburgh Meeting, Feb., 1923.

an excess of coal and coke, the zinc distilled, and an unfused mixture of coke and gangue left as a residue. In the Fulton furnace, which is the principal example of this type, the ore is mixed with coke and formed into large briquets with pitch as binder. These briquets are baked to drive off the volatile matter from the pitch and are then set up so as to form a continuous resistor through which an electric current is passed, the charge thus being evenly heated by its resistance to the current. In other furnaces of the dry distillation type the heat is generated by its resistance to the passage of an electric current between two electrodes embedded in it.

In electric smelting proper only sufficient reduction fuel is mixed with the ore to reduce the metals contained, leaving no excess carbon, and fluxes are added to form a fusible slag with the residue, allowing the lead and precious metals to separate out as bullion and the copper as matt. In this type of furnace the heat is supplied by an electric arc or by the resistance of the part of the charge and slag which lies between two or more electrodes projecting through the roof of the furnace.

Requirements for Refractories

The requirements for refractories to be used in dry distillation furnaces are less exacting than for those to be used in smelting furnaces in which a liquid slag is produced.

In the former the furnace lining is not exposed to the action of corrosive slags; and in the Fulton briquet furnace the charge does not even come into contact with the furnace lining. Under these conditions the refractories need not be especially resistant to corrosion. They should have a melting point of not less than 1600°C , and since the furnace is of large size should be of sufficient strength to support considerable weight at temperatures of from 1400° to 1500°C . They should be non-porous, to prevent the absorption of large amounts of zinc, and of uniform size to allow laying with tight joints. They must withstand rather rapid changes of temperature between about 800°C and 1400°C without spalling or cracking. In short, the requirements are very similar to those for the lining of retort furnaces.

Refractories used in the lining of electric smelting furnaces in which the residue is melted to a liquid slag must fulfill all the above requirements and in addition must resist the attack of corrosive slags at a high temperature. These slags are usually either very basic or very acidic and corresponding basic or acid refractories must be used. Since in these furnaces the heat is supplied by a buried arc or by the resistance of the part of the charge lying between carbon electrodes near the middle of the furnace, the lining is liable to be subjected to local heating considerably higher than the average temperature of the furnace, and suitable provision must be made for this in the quality of refractories used.

Since electric heat is expensive, the lining of either dry distillation furnaces or smelting furnaces is always backed up by some kind of heat insulation. For this some such material as Sil-O-Cel, having a low heat conductivity, is used. The insulating material is not subjected to a high temperature and hardly comes under the heading of refractories.

The Bricks Used in Condensers

The type of furnace used for the volatilization of the zinc does not affect the kind of condenser to be used. The temperature in the condenser varies from something below 1000°C to about 500°C. The brick used in the lining need not be very refractory, but should be dense and of sufficient uniformity in size to be laid with tight joints. In the part of the condenser in which the temperature is about 500°C or slightly higher a peculiar condition must be guarded against. The gas in the condenser is a mixture of zinc vapor and carbon monoxide. At temperatures of about 500°C carbon monoxide tends to break down into carbon dioxide and elemental carbon, according to the reaction:



This reaction is greatly accelerated by the presence of iron, which acts as a catalyzer. If the refractory lining of the condenser contains specks of iron oxide these will be reduced by carbon monoxide to metallic iron. Carbon is then deposited around this as a nucleus, and exerts sufficient expansive force to disrupt the lining in a short time.

This effect has been investigated at the Mississippi Valley Station of the Bureau of Mines and a report of the investigation was published in the August number of this *Journal*.¹

In the present retort practice condensers are subjected to much handling and last only for about ten days, but in electrothermic processes where large permanent condensers are used, the lining must last much longer than this, and the effect of carbon monoxide becomes important. It can be prevented by the use of iron-free refractories. In fact, the use of iron-free material for the lining of condensers is practically essential in the electrothermic metallurgy of zinc.

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¹ B. M. O'Harra and W. J. Darby, "The Disintegration of Refractory Brick by Carbon Monoxide," *Jour. Amer. Ceram. Soc.*, 6 [8], 904-14 (1923).

OUTLINE OF REFRACTORY REQUIREMENTS FOR THE IRON AND STEEL INDUSTRY¹

BY F. W. DAVIS

ABSTRACT

One of the greatest obstacles to the development of better refractories for the iron and steel industry has been the failure of the iron and steel men to give refractory manufacturers accurate detailed analysis of chemical, physical and thermal conditions to which the refractories are to be subjected. This paper summarizes briefly some of the conditions to be encountered in the major processes.

Blast furnace refractories may be divided according to requirements as follows: *Hearth* and *Bosh* brick should withstand the scouring action of molten iron and acid slag at temperatures around 1800°C. *Inwall* brick should be impervious to hot, reducing gases, should resist the sand blast action of the fine particles of ore carried by the gas, should have a low coefficient of thermal expansion and should possess sufficient compressive strength to support the weight of the upper part of the furnace. *Top* brick should be as dense and resistant to abrasion as possible. *Downcomer*, *Dustcatcher* and *Gas Line* brick should be dense and resist sand blast action of gas heavily laden by particles of charge. *Hot Blast Main* and *Bustle Pipe* brick should be of low heat conductivity. *Hot Blast Stove* brick should not vitrify at 900°C, should have maximum capacity for absorbing and giving off heat, and be of high compressive strength.

The by-product coke oven is becoming a big factor in the refractory fields and has major requirements as follows: *Canals* and *Ovens* require brick of high thermal conductivity which will resist sudden changes in temperature and will not be affected by reducing gases at high temperatures. *Checker* brick should have great capacity for absorbing heat.

Bessemer converters require brick resistant to slag at temperatures from 1600° to 1700°C, the nature of the slag being determined by whether the process is acid or basic.

Requirements for open hearth furnaces are as follows: *Roof* brick (both acid and basic furnaces) must not only be capable of maintaining an arch but should withstand as much as possible the action of iron oxides at temperatures of 1800°C. *Checker* brick (both acid and basic furnaces) should possess a maximum capacity for absorbing and giving off heat, and a minimum chemical affinity for oxides from charge. *Ports* (both acid and basic) must withstand the action of slag splashes, also direct action of flame. The *hearth* of the furnace consists of several courses of brick (acid or basic depending on the process) upon which is built the hearth proper by means of many layers of crushed refractory of the same nature. This crushed material must frit together at high temperatures without excessive softening.

Introduction

The part played by refractory materials in the metallurgy of iron and steel is of greatest importance, but strange to say, there is at present very little standardized information as to complete requirements for the various processes. In other words, to the present time, neither the producer nor the consumer of refractories possesses sufficient information to have a common talking point, and it could be said that we need to develop what might be termed a new set of units for refractory materials which would tell more as to their behavior in actual practice.

¹ Presented before the Refractories Division, Pittsburgh Meeting, Feb., 1923.

Many firms purchase refractories on chemical composition alone, and a few others combine chemical analysis with physical tests, but as far as I can learn, there is no standard procedure to determine the relative merits of different refractory products for the various uses for which they are manufactured.

The knowledge of the material used in the refractory is essential for proper selection. This, however, taken alone, may be very misleading for the factors of physical structure of the material, size of grinding during preparation, methods used in mixing and the heat treatment in firing are of almost equal importance.

The greater fault responsible for this very unsatisfactory condition lies with the consumers in their failure to give the refractory manufacturer an accurate and detailed analysis of the actual conditions, chemical, physical and thermal to which the desired refractory is to be subjected. With this in view it is the object of this paper to state in some detail the conditions to be encountered in the various processes, rather than to attempt to designate a particular refractory which should be used.

Blast Furnace

Probably one of the earliest consumers of refractory materials in the ferrous industry was the blast furnace operator. Under normal operating conditions, the grade of refractory used in the construction of the blast furnace will determine more than any other item the life of the furnace. With reference to refractory requirements the blast furnace itself is divided into three major zones, the hearth and bosh zone, the inwall zone and the top zone, each differing from the other as to requirements.

Hearth and Bosh.—The “hearth” and “bosh” bricks must be of a material which will resist the scouring action of molten iron and a more or less acid slag. They should be sufficiently dense to prevent penetration to any great extent of the molten material. There should be no appreciable shrinkage at the temperatures (1800°C) to which they are exposed. They should be of uniform and regular dimensions to permit being laid with minimum-sized joints. There will be very little abrasion in this section and the greatest load they will normally be called upon to carry will be little more than the weight of the molten iron and cinder plus the blast pressure.

Inwall.—Brick for the *inwall* or middle section of the furnace will not be subjected to such severe chemical or thermal conditions. They will, however, be subject to considerable abrasion due to the movement of the burden as well as the “sand blast” action of the ascending gas heavily laden with small particles of the burden. These brick must have sufficient compressive strength to support the weight of the upper part of the furnace. A low coefficient of thermal expansion is desired to avoid

any distortion of shape on heating. Another factor to be considered in connection with the brick to be used in this section is the permeability to gases at high temperatures. This is a most important factor due to the destructive action of carbon monoxide in contact with the iron oxide present in the brick. In this connection, too, there are certain metallic vapors present when smelting ores of some localities which penetrate the brick with very destructive and sometimes disastrous results; zinc is the greatest offender in this respect.

Top.—In the *top* section of the furnace the conditions of abrasion are extreme and the temperatures are at a minimum, hence the brick should be as dense and resistant to abrasion as possible, at the expense, if necessary, of the refractory qualities. It is just as essential that the top brick resist abrasion as it is to have a highly refractory brick in the high temperature zone, for as soon as the top brick wear away to any great extent, there will be unequal distribution of the burden which in time will necessitate blowing out for repairs.

Pipe Linings.—The brick in the *downcomer*, *dustcatcher* and *gas lines* will be subjected to the “sand blast” action of the gas and should resist abrasion. For the *hot blast mains* and *bustle pipes* the idea is to conserve as much heat as possible so that a brick of minimum heat conductivity is desirable.

Stoves.—The *hot blast* stoves constitute the largest auxiliary to the blast furnace and require more brick of a special nature than any other unit including the furnace itself. The function of the hot blast stove is to absorb as much heat as possible from the combustion of a portion of the top gas and deliver this heat with maximum efficiency to the air being blown into the furnace. For this reason it is of greatest importance that the brick used will absorb a maximum amount of heat and give it off readily to cold air being blown through. The temperatures will run as high as 900°C and the brick must not vitrify at this temperature. In addition to this the brick must have high compressive strength.

By-Product Coke Oven

One of the more recent users of refractory material and at the same time one which is well in the lead as regards tonnage required is the by-product coke industry. In the by-product coke oven we have two major classifications, namely, the brick used for the canals and ovens, and the checker brick.

Canals and Ovens.—For use in *canals* and *ovens* the brick must have a high thermal conductivity to promote rapid coking. They must resist sudden changes in temperature which will be encountered in the charging and pushing operations. The coefficient of thermal expansion should be low. The chemical analysis of this brick should show no element which

will be acted upon by the highly reducing gas to the detriment of the physical properties of the brick.

Checker.—The major requirement of *checker work* brick is to be able to absorb the maximum amount of sensible heat from the waste gases passing through the checkers and to give it up to the cold air in the other portion of the cycle of operation.

Bessemer Process

The refractories used in the acid Bessemer process are subject to the action of a highly siliceous slag at a temperature of from 1600° to 1700°C. The greatest trouble encountered with refractories in this service is found directly around the tuyères, where the iron oxide slags the acid lining away. For this reason the bottoms of the converters are made separate so as to be readily replaceable.

The basic Bessemer process is little used in this country because of our lack of high phosphorus pig. In this process the slag is highly basic so that the lining will of necessity resist a hot basic slag. There will also be some accumulation of the oxides of phosphorus silicon and sulphur which may be detrimental to the lining.

Open Hearth Process

The open hearth process is divided into two major divisions, acid, and basic. For general consideration of the furnace, aside from the hearth section, no marked difference is shown between the two processes. The checkers, gas mains and roofs used are the same in both.

Checker.—Inasmuch as over 75% of the total heat charged to the open hearth furnace leaves as sensible heat in the gas, one may readily see the importance of having efficient regenerators. The brick used will be subjected to temperatures as high as 900°C and from time to time splashes of slag, either acid or basic as the case may be, will find their way to the checkers. In addition to this, the flue gas is always charged with fine oxide particles from the bath which have a tendency to impinge and fuse on the checker brick. From this it is evident that the desirable qualities for checker brick are a maximum capacity for absorbing heat with a minimum affinity or slagging action with oxides from the charge and the slag itself.

Roof.—The roof of the open hearth furnace has proven in most cases the limiting factor in the life of the furnace, and is the point at which the greatest economy might be accomplished by improved refractory materials. In present practice, open hearth roofs are built of the purest silica brick obtainable. In spite of the fact that every effort is made to prevent the direct impingement of the flame on the roof, this section is one of the hottest parts. Together with the intense heat of about 1800°C,

the roof is subject to an atmosphere containing considerable concentration of oxides of iron. The effect of the iron oxides is readily seen on the examination of roof brick taken from service in that the lower half will be completely impregnated with iron and the structure of the brick destroyed. Under these extremely severe conditions, brick used in a roof must possess sufficient strength to maintain an arch and support their own weight.

Ports.—The “ports” of the furnace must also be constructed of the highest grade refractory material as these parts are subject to the direct play of the flame as well as the iron oxides and some slag splashes.

Hearth.—The hearth of the open hearth furnace is usually built up primarily of brick either acid or basic according to the process, and then filled in with similar crushed material. This filling material must be extremely refractory and have a long range of vitrification, *i. e.*, must frit together at high temperatures without fusion or excessive softening.

For the basic process in connection with the above, the refractories used in the hearth must be burned until they shrink, and become very dense and must be of such a nature as not to slake readily. They will be subjected to the action of carbides, phosphides and silicides to a limited degree.

In the basic process it is necessary to provide a high grade neutral refractory which is placed in the furnace wall between the basic hearth section and the acid wall to prevent these two from action with each other. In many plants the ports are covered with neutral brick as well to prevent the basic slag from splashing on and damaging the acid brick used for this portion.

Crucible Steel Process

Crucibles for making steel were formerly made of fire clay. The American practice, however, is to use 50% fire clay and 50% graphite which increases the life of the crucible about 100%. Crucibles in steel making are subject to very severe mechanical strains at high temperatures as well as slagging action at the top of the molten steel.

Furnaces for Reheating, Annealing, Tempering, etc.

Under this group will fall all of the furnaces for the further refining and finishing of steel, the requirements for which as to refractory materials can, in a general way, be said to follow the trend of the open hearth in a somewhat less exacting degree. The temperatures used in these furnaces should never approximate the open hearth furnace temperatures and the only slag found here will be formed from the oxides of iron formed during the process of heating. When checkers are used, the same specifications will apply as with the open hearth. The roofs though subject to some-

what lower temperatures must have practically the same characteristics. The hearths or "bottoms" as designated in these furnaces are required only to retain the iron oxide cinder formed in the heating.

MILFORD, DELAWARE

METALLURGICAL REQUIREMENTS OF REFRATORIES IN COPPER SMELTING AND REFINING¹

BY FRANCIS R. PYNE

ABSTRACT

The requirements of refractories in the copper industry may be classed as follows:

1. Resistance to temperatures
2. Resistance to chemical action
3. Ability to withstand sudden temperature changes
4. Minimum absorption of slag and metal
5. Absence of manufacturing defects.

Resistance to Temperature

The ability to withstand high temperatures is in general of importance only in the reverberatory smelting of fine ores. Here we have a furnace approximately 100 feet in length into which the roasted ore is charged at one end while the molten slag and matt collect at the other end. And as the object of this operation is to smelt the greatest possible tonnage in a given space of time, it follows that the higher the temperatures obtained, the better. It is therefore apparent that in this case the refractory that will withstand the higher temperature, other conditions being equal, is more desirable.

In other metallurgical operations, such as roasting, converting and refining, the temperatures are not excessive and in these operations the question of refractoriness is of secondary consideration.

Resistance to Chemical Action

Resistance to chemical action is of the greatest importance. The copper metallurgist deals with highly corrosive slags, matts, oxides, and metals and unless the proper refractory is selected for each material, there will be constant interruptions to the process due to shut downs for repairs. As the products formed in the smelting of copper ores are strongly basic, the natural tendency is towards the basic refractories such as magnesite and chrome. For roof work, however, silica is almost universally used except in the case of very low temperature work or where the silica would be subjected to such corrosive action of slags, flue dusts, etc., as to make its use uneconomical.

¹ Presented before the Refractories Division, Pittsburgh Meeting, Feb., 1923.

Clay brick is commonly used for flues, for side walls and roofs in low temperature work and almost universally for fireboxes in coal fired furnaces. Due to the high price of the magnesite and chrome refractories, there is a constant endeavor to keep their use down to a minimum and to substitute clay brick whenever possible. This is particularly desirable in refining operations where the slags formed are not as highly corrosive as in the smelting operations, but nevertheless are very basic.

However, clay refractories vary from highly siliceous to neutral and there must be considerable care exercised in their selection not only for furnace linings but for fireboxes. A highly siliceous clay refractory will not withstand basic slags, neither will it withstand a corrosive ash from the coal, and it is generally necessary to use the more neutral clays for this work, although there are, of course, exceptions due to local conditions.

Many producers of clay refractories do not appear to realize the importance of the chemical composition of their products. As long as their product will stand a proper fusion test they appear to be satisfied and seem to feel that the consumer who desires to know something about the chemical composition, is technical and not practical. The writer has known instances where the manufacturers of clay refractories have had no analyses made of their product for years. However, there are indications that such conditions are changing for the better.

Sudden Temperature Changes

The ability to withstand sudden temperature changes is desirable as in many operations there is a sudden increase or decrease in the temperatures of operation. Unless the refractory possesses this ability, it will spall badly and have a short life.

Minimum Absorption of Slag and Metal

One of the very important requirements for copper refractories is the ability to withstand penetration of slags, matts, and metal. As the products are of considerable value it follows that if the refractories are porous they will tie up a lot of copper, silver, and gold which means not only a heavy interest charge but also a heavy expense in the retreatment to recover these metals, which adds greatly to the cost of operation. It also follows that any refractory, irrespective of its chemical composition, that is so porous as to permit of considerable absorption by capillary attraction, will have its properties so changed as to be destroyed in a relatively short time.

Obviously, the cure for porosity in refractories that come in contact with molten materials lies in the use of as dense a brick as is possible, and this generally requires fine grinding and machine pressing. Or else the result may be accomplished by the use of a refractory that will become

slightly glazed at the operating temperature and close up the pores. However, to the writer's knowledge, this type of refractory has not as yet been satisfactorily developed.

Absence of Manufacturing Defects

The absence of manufacturing defects is very desirable but unfortunately, like death and taxes, they are still with us and are a source of considerable annoyance. The chief defect lies in non-uniformity of product in that straights and shapes are frequently made of different material, have different fineness of grind, and different degrees of firing. The same shape may also vary widely. On this account it is not surprising that the mechanical properties are not similar and when refractories having such different characteristics are placed side by side in a structure and subjected to the same operating conditions, that failures frequently occur.

Irregularity in the thickness of the individual pieces makes it necessary to have thicker joints than are desirable and will frequently cause local failure. Warped surfaces, though slight, are fertile sources of weakness. Fire cracks, defects in molding, setting, or firing may become very serious as they not only adversely affect the quality but this effect is greatly magnified at increased temperatures.

As practically all refractories are subject to further change in volume upon heating for long periods, particularly the clay refractories, it becomes of importance that they should be fired at a temperature not less than the maximum temperatures at which they are to be used. Unless this is done there may be such an excessive volume change during the operations as to break down the structure in which the refractory is used. It is, generally speaking, probably true that the harder a refractory is fired in the kiln, the more satisfactory it will be.

ELIZABETH, N. J.

REFRATORIES FOR STOKERS

BY GEORGE I. BOUTON

ABSTRACT

An outline is given of the general uses of refractories for stokers, and the requirements for an ideal fire brick. Temperatures which a refractory must stand are given and some of the troubles due to fluxing and spalling are described. Some analyses are made of typical brick and troublesome ash.

Introduction

Uses of Refractories.—It would be difficult to imagine a stoker without refractories forming some part of its setting, or the connection between the stoker and the place of use for the heat which has been liberated. Even the small underfeed stoker placed in the furnace of a Scotch marine

boiler has need of some refractories. The overfeed stokers, the inclined side feed, the inclined front feed, the traveling grate, all need arches and various inclosing walls. The underfeed stokers from the little single retort to large multiple retort, require inclosing walls, and in some cases, covering arches; some of these are getting more and more difficult to maintain. If the refractories fail to stand the strain the stoker manufacturer is the loser. Naturally he is more or less interested in refractories.

Requirements of a Refractory

If the stoker man could get it, he would like a refractory that would act as a reflector to aid the heat on its way to the place of use; one which will not change size or shape with changing temperatures; one which will not absorb or transmit heat; one which will not combine chemically with the products of combustion, or the waste material carried by the products of combustion; one which will stand considerable load at high temperature; one whose pores are fitted with double acting check valves to prevent leakage in either direction; one which will not get tired and drop on to the fuel bed, or other inconvenient place at inopportune times. Such a refractory is the kind we should like to find.

The user of a refractory is not interested in why it fails except to prevent a repetition of failure.

Tendency toward High Temperatures.—There is a continual tendency toward higher temperatures through reduction in excess air. With air at 70°F a high grade coal burned with 20% excess air and without radiation or other losses would produce about 3770°F. If the air were preheated to 270°F, the resulting temperature would be about 3930°F.

Fluxes Injurious to Refractories.—All coal carries ash, and this ash is made up in part of material which, at furnace temperatures, forms an active flux for refractories. Where the percentage of fluxes in the ash is small, the ash is not troublesome.

A refractory which would stand up three or four years in average service with the general run of coal might fail in forty to sixty days in the same service with coal having an ash high in fluxes. The writer's attempts to find a brick which would withstand the fluxing of the ash have not been particularly successful. It has usually been necessary to advise a change in coal. Under the market conditions of the last six or seven years, changing coal has not been easy.

Several years ago I asked a refractory expert whether there was a brick made which would stand up under the bombardment of fluxes. He told me that I ought to be satisfied with a brick that served satisfactorily in 90 or 95% of the installations. He failed to appreciate that failure in 5 or 10% of the cases might be very serious and expensive.

A refractory which was right chemically and which would also stand other strain would be universally useful for stoker furnaces.

As the writer's early troubles with fluxing were with brick running about 66% silica, the natural thing was to try a brick higher in alumina. So far the attempts have not been successful, as shifting the trouble from fluxing to spalling has not helped matters.

Difficulties from Spalling.—Failure in a few months due to spalling is more serious and annoying than failure in a similar length of time due to fluxing, for the field of failure is much more extensive, since it is not limited to plants burning particular coals. "Spalling," when it happens to be in large pieces, two or four inches thick, is called "slabbing."

So far as the writer's experience goes, brick running more than 40 or 42% alumina have spalled seriously. Whether spalling is due to insufficient bonding power of the clay or to structure or to some fault in the process of manufacture, I shall not attempt to say. We need brick running fairly high in alumina now, and will need them more in the future.

Some of the brick which I have analyzed are as follows:

TABLE I						
	1	2	3	4	5	6
Silica	66.66	59.00	53.00	51.58	48.05	43.80
Alumina	31.32	38.06	43.99	46.07	46.62	51.55
Iron Oxide	0.58	0.71	1.43	1.63	2.42	2.73
Lime	.50	.80	0.60	0.34	1.30	0.55
Magnesia	.45	.68	.30	trace	0.20	.45
Titanium Oxide	?	.43	?	1.06	.10	.32
Alkalies	0.28	...	0.54	0.10	trace	...
Melting Point } Degrees F }	3110	3047	3092	3074	3083	3164

Numbers 1 and 2 have not seriously spalled. Numbers 3 and 4 spalled considerably, while 5 and 6 spalled very badly.

Analyses of the coal, the ash and the slag formed on the brick in a case where the brick were badly slagged, were as follows:

TABLE II					
Slag from Comb. Chamber, Southern Ill. coal				Ash from W. Va. coal	
1. Glassy	2. Reddish	3. Dark gray		Slag	
49.45	53.50	57.69	Silica	48.95	41.91
25.36	31.46	28.43	Alumina	25.10	18.41
5.74	4.76	3.99	Iron Oxide	16.17	24.80
6.05	7.56	7.38	Calcium Oxide	4.17	11.28
1.55	1.03	1.03	Magnesium Oxide	1.05	1.95
None	1.69	1.49	Alkalies	3.26	1.23
			Melting Point		
			Degrees F	1980	
			The brick was No. 1 of Table I.		

Relative Price of Refractories.—The price of a refractory at the kiln is a portion, usually a small portion, of the cost of that refractory in place ready for service. Adding 50% to the price of the refractory at kiln will add 20 or 25% to the cost in place. If adding 50% to the price at the kiln will obtain a brick which will give 100% increase in life, it would appear to be good business to buy the higher-priced brick. Unfortunately, much of the buying is done by people who can see only the price. Some of the trouble is also partly due to the fact that the person selling the brick starts out with the idea that the only way to sell is to name a low price, and the business is taken at a price which means a present to the purchaser or an inferior brick.

I mentioned above the tendency toward increase in furnace temperatures. Where the walls are outside walls, and as in the old days, only eighteen inches thick, the refractory is helped out by radiation from the outer surface. This assistance is being eliminated by increasing thickness of the walls, and by the addition of insulating brick. An ordinary red brick will stand a considerable furnace temperature if it is thin enough and if it is sufficiently cooled by air circulation. There is a possibility of helping matters by taking the air supply through ducts built in the walls, inside the insulating brick, but this will materially complicate the setting and air supply particularly in the case of large forced draft stokers.

In spite of all ameliorating conditions, it will be necessary to deal with continually increasing temperatures. What is needed is a brick which will stand a very high temperature; one which will not spall; one which will stand pressure at the temperature of use and one which will resist the fluxing action of ash.

DETROIT, MICH.

THE VALUE OF UNIFORM FIRE BRICK FROM THE STAND-POINT OF THE CONSUMER¹

BY R. F. HARRINGTON

Introduction

Our experience with refractories for large tonnage air furnaces melting high grade cast iron, has been principally from Grahn, Kentucky, Cumberland, Maryland and Clearfield, Pennsylvania.

The use of large amounts of brick from all of these sources in our practice has led to the definite conclusions, namely that:

(1) From any of these districts it is possible to obtain brick generally satisfactory for our furnace practice.

¹ This paper was presented before the Refractories Division, Pittsburgh Meeting, Feb., 1923.

(2) The clays from certain districts are better suited for certain purposes than clays from other districts; and furthermore, only with careful testing of the brick under careful and scientific supervision can the brick best suited to a given purpose be determined.

(3) Brick from manufacturers in all districts frequently exhibit marked differences from shipment to shipment in service rendered.

Most important of all from the consumer's standpoint, is the lack of uniformity from shipment to shipment. A large amount of delay and monetary loss to the consumer is incurred by failure to receive brick of uniform quality, especially in reference to the important properties of refractoriness and the resistance to spalling. Frequently initial tests on carload lots indicate unusual possibilities, but subsequent shipments fall far below the results obtained on initial test. The writer does not believe for one moment that this condition exists because of any desire on the part of the manufacturer to misrepresent his brick by unusually good quality on initial tests. Rather does it indicate the difficulty of the problem when it is realized that the manufacturer would certainly do everything in his power to have at least his initial brick representative of brick that he could furnish under normal conditions.

In many instances we have used thousands of brick with entire satisfaction from different producers only to have two or three carloads of brick received which were entirely unsatisfactory for our work.

Conditions demanding immediate use of these brick often meant that an entire furnace was built of inferior brick. Again, a few of these brick may be placed in a roof in conjunction with good brick and after a few heats cause the failure of the entire roof, with consequent loss of the good brick as well as the inferior brick. It is such results as these, with the consequent delays, that are of much concern to the consumer.

I desire to point out that these conditions are not conditions obtained only under poor furnace control, or the use of inferior grades of coal, but occur with furnace conditions under absolute control, unchanged design and unchanged supply of coal.

Often as further evidence to convince the brick manufacturer, whose representative may be on the job, that conditions are as have been stated, a few courses of the brick under question alternated with other brick show very clearly the melting or spalling of the inferior brick.

At what conclusion can the consumer arrive other than the fact that the producer in many instances has failed to give proper supervision in the manufacture to insure proper handling of material, or that the clays involved have changed in character with consequent bad effect on the final product.

Where it has been suspected that the clays have been at fault the scientific investigations by the Mellon Institute, or similar institutions or organi-

zations, have indicated the cause and ultimately the trouble has ceased.

The writer desires to state that invariably the producer has made an effort to correct the condition once he has been convinced that the difficulty has been one involving the manufacturer. However, this effort on the part of the manufacturer is all post-mortem.

It would seem that a great deal of this trouble could have been eliminated had the manufacturer taken full recognition of the value of scientific control methods in reference to the analyses and testing of the clays and the manufacture of the product.

HUNT SPILLER MFG. CORPN.
BOSTON, MASS.

REFRATORIES FOR FLAT ARCHES¹

BY JUSTIN E. HARLOW

ABSTRACT

Arch construction is discussed, describing present method of placing fire clay tile. Tile are suspended on cast iron hangers by means of a tee-shaped slot molded in the top end of each tile, giving room for expansion in every direction. Larger quantities of heat units are released, more intense chemical reactions and there is ample shearing strength and small loss from weight or pressure.

Introduction

This paper is written with the idea of conveying to the reader, in brief, the qualities that seem most desirable in fire-clay tile for use in flat suspended arches.

In flat arch construction, the tile are suspended on cast iron hangers by means of a tee-shaped slot, molded in the top end of each tile. Thus, each tile hangs as a separate unit, free to expand in every direction. In the old curved or sprung arch, each brick or unit was held in place by the pressure due to the weight of the arch on each other, the side thrust being taken up by iron buckstays and steel rods. In the flat arch any side expansion or thrust is taken up by a layer of dry asbestos. The construction of the suspending members makes it very easy to thoroughly ventilate the top of the tile by currents of air. This prevents the tile from becoming soaked with heat, softening and deteriorating rapidly under the action of ash slag and corrosive gases.

In the matter of service, efficient operators release far larger quantities of heat units under the arches in a given time than formerly. The chemical reactions are the same as the refractory man has always encountered, but probably more intense because of the greater quantities. Thus, the changed form of furnace roof and the undivided attention of the arch manufacturer has simplified the problem of the tile man.

¹ Read before the Refractories Division, Pittsburgh Meeting, Feb., 1923.

The tile are not subjected to great weight or pressure. The shearing strength is ample. Owing to the fact that the tile are suspended, it is not necessary to dip them; but they should be buttered to seal the joints to prevent heat penetration. To make a joint that is thin and satisfactory, it is very important that the tile should have flat surfaces and square angles, and be true to dimensions. The tile should be coarse in texture; the flint particles should be sharp and not larger than one-quarter of an inch in the greatest dimension. The tile should be highly refractory and able to withstand temperatures as high as 3000° to 3200°F . They should be burned to a point just short of entire elimination of the initial shrinkage, and by no means vitrified. The color should be a deep cream, and each shipment should be uniform. The writer prefers to see the iron spots just showing. The best material only should be chosen and handled in the manner your experience has found best, especially in such matters as weathering, calcining raw clay, grinding, etc.

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EFFECTS OF ACCELERATORS AND RETARDERS ON CALCINED GYPSUM¹

By F. C. WELCH

ABSTRACT

Theories on the setting and the effects of accelerators and retarders on calcined gypsum are outlined. Accelerators and retarders as found by the writer and several other investigators are given, with comparative effect and any noticeable advantages or disadvantages of such instruments.

Introduction

Rate of Setting Controllable.—One of the most valuable properties of calcined gypsum is that it can be made to harden or “set” in any predetermined length of time at the will of the user. A dentist taking a plaster cast of a mouth uses material accelerated to set in not more than three minutes; a plasterer working on a large wall may use the same material retarded to set in not less than six hours. The ability to control this property has been taken advantage of commercially, so that nearly all of the calcined gypsum products now sold are accelerated or retarded to satisfy the wishes of the purchaser.

The Chemistry of Setting.—The chemical process of the setting of plaster is still a much mooted question. As far back as 1765 Lavoisier² gave the following explanation: “If, after having removed the water of hydration from gypsum by fire, it be returned to it (commonly called gaging the plaster) it takes up the water with avidity, a sudden and irregular crystallization takes place, and the small crystals which are formed becoming confused with one another a very hard mass results.”

As all anhydrous salts do not set when taking up water to re-form the hydrate some further explanation is necessary. In 1887 Le Chatelier³ wrote: “On mixing burnt plaster with water each particle soon becomes surrounded by a layer of a solution which is saturated with regard to the hemi-hydrate but strongly supersaturated with regard to the stable gypsum. Crystallization of gypsum soon begins, either spontaneously or more probably from nuclei which have persisted unchanged throughout the burning process. Growth of the crystals taking place from many neighboring centers, radiating groups are formed, and the interlocking of these is at least one of the causes of the strength of the mass.”

Desch⁴ says any salt in which the anhydrite is much more soluble than the hydrate will do likewise saying that anhydrous sodium sulphate mixed

¹ Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

² Lavoisier, *Compt. rend.*, 1765; *Oeuvres Compl.*, 3, 122 (1765).

³ H. Le Chatelier, “Thesede doctorat.”

⁴ C. H. Desch, “The Setting of Plaster,” *Trans. Ceram. Soc. (Eng.)*, 18, 15 (1918).

with a small amount of water, and temperature kept below transition point will set in the same manner as gypsum.

Setting a Colloidal Process.—From an entirely different viewpoint several investigators define the setting of plaster as a colloidal process. Cavazzi¹ claims that calcined gypsum when mixed with water forms a colloidal intermediate gel from which needle-like crystals sprout. Traube² agrees with Cavazzi. Cavazzi mixed five grams of $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ in 25 cc. of water at 15°. After five minutes 25 cc. of alcohol was added to the clear filtrate. The salt separated out in a gelatinous form which under the microscope later formed needle-like crystals. Cavazzi claims that this result is in harmony with the theory of P. P. von Weiman. Von Weiman claims that the transition of a compound in the solid state in a super-saturated solution is in the form of needle crystals if the compound is not very soluble. If on the other hand the compound is very soluble it separates out as a colloidal gel. Cavazzi claims the second case to be that of gypsum.

When calcined gypsum sets the volume occupied by the set material is greater than that of the liquid mixture. This property is made use of in molding plasters, etc. Theoretically there should be a contraction in the absolute volume of the material:

Specific gravity	Formula weight
$\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O} = 2.62$	$2\text{CaSO}_4 \cdot \text{H}_2\text{O} = 290$
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O} = 2.32$	$\text{H}_2\text{O} = 18$
	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O} = 172$
$\text{volume before setting } \frac{290}{2.62} + \frac{3 \times 18}{1} = 164.6; \text{ volume after setting } \frac{2 \times 172}{2.32} = 148.1$	

The supporters of the colloidal theory of setting attribute this expansion to the separation of crystals from the coagulated gel, while Desch claims it is due to the pushing apart of the crystals of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. Davis³ after studying the setting of calcined gypsum under the microscope says that at first an orthorhombic modification of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ is formed which then changes to a monoclinic form. He attributes the expansion to the above change.

Means of Controlling Rate of Setting.—While a great many substances have the ability to accelerate or retard the setting of calcined gypsum trade practice has pretty generally adopted the use of a few accelerators, gypsum, alum, and zinc sulphate, and one retarder, a packing house product similar to glue and of indefinite composition. It is known to the trade as "retarder."⁴

¹ A. Cavazzi, *Koll. Zeit.*, **12**, 196 (1913).

² J. Traube, *Koll. Zeit.*, **25**, 62 (1919).

³ W. A. Davis, "The Nature of the Changes Involved in the Setting of Plaster of Paris," *Soc. Chem. Ind. Jour.*, **26**, 727 (1909).

⁴ U. S. patents, Nos. 1,106,777 and 1,308,644.

Some physical factors,¹ such as per cent mixing water, temperature of mixing water, amount of stirring, size of particles, age after calcining, and age after grinding, have an effect on the time of set. All seem agreed that a decrease in mixing water increases the time of set. However, there is a difference of opinion as to the effect of the temperature of the mixing water. Ostwald shows that freshly calcined $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ sets more rapidly than the same material aged and that the grinding of the aged material hastens the time of set.

This Investigation

Purpose.—It is the purpose of the present paper to give a summary of the effects of admixtures on the time of set of $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ in relation to the amount of the admixture required, and advantages or disadvantages of such admixtures for certain desired effects. Calcined gypsum is very sensitive to the effect of some accelerators and retarders, and in some cases both the hardening action and end product are quite different than in others, even though the setting has been retarded the same amount in each case. For instance, a dense hard product might be desired. By mixing with a 2% solution of gum arabic the plastic mixture might be worked about 35 minutes, and a denser, harder product obtained. However, for use as pottery plaster this would not be satisfactory, as even though a harder product would be very desirable the absorption is lowered.

Determination of Rate of Setting

Vicat Needle Method.—The setting of calcined gypsum is not an instantaneous reaction; the paste of calcined gypsum and water first thickens, then solidifies and finally becomes hard. The time of set is usually measured by the Vicat needle.² To study the behavior of accelerators and retarders, it is desirable to be able to plot a curve showing the relation between the development of set and the time. The Vicat needle permits of the determination of only one point on such a curve. It was therefore abandoned in favor of the "time-temperature" and the solubility methods. The progress of the reaction was followed by frequent microscopic examinations, and the degree of hardening finally attained was indicated by measurement of the tensile strength of the material when seven days old.

¹ F. F. Householder, *Jour. Amer. Ceram. Soc.*, **1** [8], 578 (1918); W. Ostwald and P. Wolski, "Contributions to the Dispersoid and Colloid Chemistry of Plaster," *Koll. Zeits.*, p. 78 (1920); C. H. Kerr and R. J. Montgomery, "Influence of Variations in Water Addition, Lime Addition and Temperature on Setting of Plaster of Paris," *Trans. Amer. Ceram. Soc.*, **18**, 180 (1916).

² W. E. Emley, "Measurement of Time of Set of Calcined Gypsum," *Trans. Amer. Ceram. Soc.*, **19**, 573 (1917); "Tentative Methods of Test for Gypsum and Gypsum Products," *A. S. T. M.*, C26-21T.

Time-Temperature Method.—The “time-temperature” method has been described in a previous paper by Emley.¹ Briefly, it comprises measuring the temperature of a mixture of calcined gypsum and water at different intervals of time. The setting reaction is accompanied by an evolution of heat, which with proper precautions is indicated by a rise in temperature. However, the mixture ceases to be workable long before the setting reaction has reached completion, so that, while this method may be taken to indicate the progress toward complete reaction, it cannot be used to measure the “time of set,” *i. e.*, the time at which the material is no longer workable. Typical “time-temperature” curves are shown in Fig. 1. From these curves it will be noticed that immediately after mixing there is a rise in temperature and later a still greater rise. In some cases a slight drop in temperature was noticed after the first rise but in

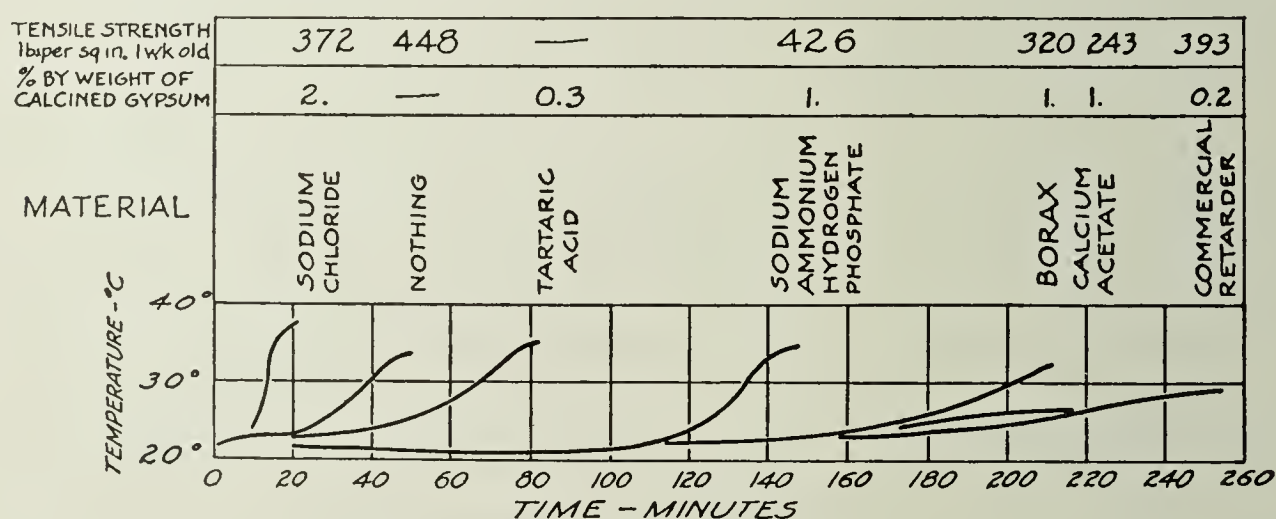


FIG. 1.

other cases this was not noticeable. Canals² claims that there is (1) a rapid rise due to hydration (2) a drop due to solution of the gypsum (3) a rise due to crystallization.

Solubility Method.—The solubility method is based upon the amount of gypsum or $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ in solution from the time of mixing to the time when the mixture is no longer workable. As $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ is much more soluble than gypsum it seems that in the beginning the concentration of CaSO_4 would be greatly in excess of the amount of gypsum in a saturated solution.³ As the $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ changes to $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ a supersaturated solution of the $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ is formed. From the curves in Fig. 2, it would appear that the CaSO_4 in solution reaches a maximum in a few minutes, then decreases as the time of setting approaches, which seems to show that $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ crystallizes more rapidly than the $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$ dissolves.

¹ *Ibid.*

² E. Canals, “Action of Some Chemical Substances on the Duration of the Setting of Plaster,” *J. Pharm. Chem.*, **14**, 33 (1916).

³ C. Marignac, *Arch. Sci. Phys. Nat. (Geneva)*, **48**, 120 (1873).

The presence of a foreign material in solution or suspension in the water may increase or decrease the solubility, and therefore the rate of solution of the $\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$. It may increase or decrease the solubility of the $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, thereby elevating or depressing the degree of supersaturation necessary to start crystallization. Or, it may have an effect peculiar to the foreign material. On the above basis Rohland¹ claims that generally substances increasing the solubility of the hemihydrate are accelerators, while substances decreasing the solubility are retarders. Desch and Canals agree with this theory. Traube holds that the setting of the calcined gypsum is due to the coagulation of the gypsum gel, which is accelerated by the addition of electrolytes and retarded by colloids. The acceleration of salts is greatest with the univalent cation with a secondary effect of the anion. The bivalent cation has a lesser accelerating effect and the quadrivalent cation has a retarding effect.

It has been pointed out that contrary to Rohland's theory many sulphates have an accelerating effect, also that $\text{NH}_4\text{C}_2\text{H}_3\text{O}_2$ has a retarding effect. Likewise, according to Rohland himself some substances such as NaCl which increase the solubility of CaSO_4 in solution have an accelerating effect in dilute solutions and a retarding effect in concentrated solutions of the admixture. Rohland attributes the retarding effect of concentrated solu-

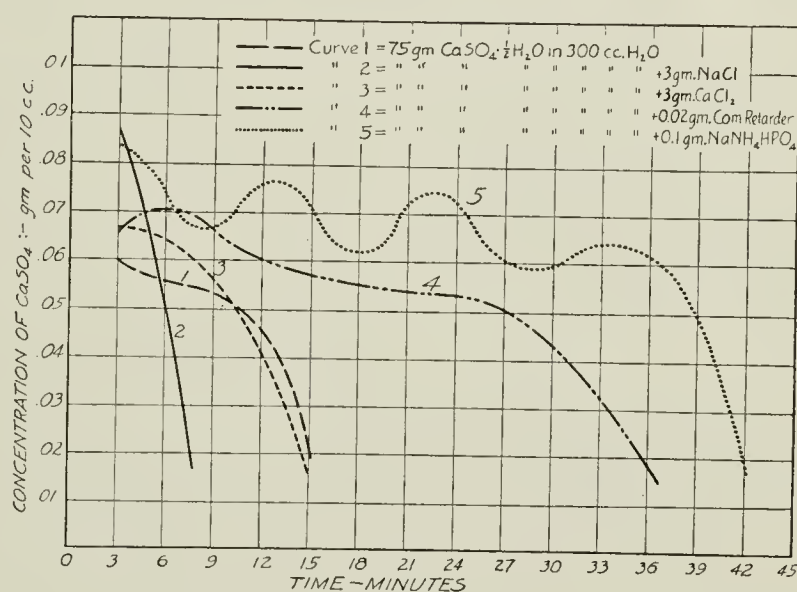


FIG. 2.

tions of NaCl to the formation of complex ions. Calcium sulphate has a propensity for forming double salts and this might account for the accelerating effect of some sulphates.

As the result of a large number of experiments conducted at the Bureau, though the effects of admixtures seemed in general to conform to both the above theories, exceptions were found in each case. For instance, if salts that increase the solubility of calcium sulphate in solution accelerate why does ammonium acetate retard the set? If the acceleration is due to the electrolytic effect of the cation of the admixture with a smaller secondary effect of the anion why do soluble phosphates retard the set? Of course as Rohland says a metathetical reaction might take place with the formation of complex ions. Also the formation of double salts may have a decided effect on the time of set.

¹ Rohland, *Zeits. für Elek.*, 14, 421 (1908).

No explanation of the above effects will be attempted at this time. Though much work has been done on the effects of accelerators and retarders due to the increasing or decreasing of the solubility of the calcium sulphate, no really broad research has been attempted on the basis of the colloidal theory.

In this paper a large number of accelerators and retarders as found in the present work and lists by other investigators will be given. We have endeavored to classify them with respect to their effectiveness and to give any outstanding advantages or disadvantages of such substances.

Accelerators

1. Certain inorganic salts seem to increase the solubility of calcium sulphate in solution. They also accelerate the "time of set." Such accelerators are soluble halides and nitrates.

2. Another type of accelerator is one having the same crystal form as gypsum. The presence of such a material would tend to promote crystallization without requiring the usual degree of supersaturation. Gypsum itself is an example of this type of accelerator.

3. Water glass, if used in large percentages, causes a hardening immediately upon addition. While this can hardly be called setting, it has been found useful along other lines.

Retarders

1. Commercial "retarder," glue, casein, and tannic acid, are the most effective retarders. Small amounts are required in each case. For in-

TABLE I

ACCELERATORS AND RETARDERS¹

NaCl	{ dilute concentrated	accelerator retarder	Na ₂ SO ₄	{ dilute concentrated	retarder accelerator
KCl		accelerator	(NH ₄) ₂ SO ₄	{ dilute concentrated	retarder accelerator
KBr		accelerator	MgSO ₄	{ dilute concentrated	retarder accelerator
KI		accelerator	Al ₂ (SO ₄) ₃	concentrated	accelerator
NH ₄ Cl		accelerator	Na ₂ Si ₂ O ₃		accelerator
NH ₄ F		accelerator	HCl		accelerator
CaCl ₂		retarder	HNO ₃		accelerator
MgCl ₂		accelerator	H ₂ SO ₄		accelerator
NaNO ₃		accelerator	C ₂ H ₅ OH		retarder
KNO ₃		accelerator	C ₁₂ H ₂₂ O ₁₁		accelerator
NH ₄ NO ₃		accelerator			
Mg(NO ₃) ₂		accelerator			

¹ Rohland, *loc. cit.*

stance, 0.2% of commercial retarder will increase the time of set two and one-half to three hours. It is believed that such substances act as protective colloids.

2. Alcohol, sugar, and soluble citrates decrease the solubility of the calcium sulphate and retard the time of set. If the "time of set" is affected by a decrease or increase of the solubility of the calcium sulphate in solution these may be considered as the retarders corresponding to the accelerators of group I.

3. Certain substances have what appears to be individual effects. Calcium acetate, for example, changes the crystal form of the gypsum in such a way as to decrease the strength of the set material. Soluble phosphates act as retarders, but instead of giving a slower end effect as most retarders, they give a very rapid rise in temperature as accelerating materials. (See "time-temperature curves.")

Soluble calcium salts and soluble sulphates (except gypsum) may either retard or accelerate the "time of set." Though at times there is a retardation it is not enough to be of practical value. Some are very effective as accelerators dependent to an extent on the amounts used.

Relation of Degree of Retardation to Other Properties

During the course of this investigation some interesting observations were made as to the relation between the degree of retardation and other properties of calcined gypsum.

Tensile Strength.—Acceleration results in the formation of smaller crystals with, consequently, a slight lessening in the tensile strength. The total effect, however, is practically negligible.

Hardness.—Retarders have a decided weakening effect. A certain amount of water is essential for the proper hardening of calcined gypsum. More water than is thus required is always added in order to properly mix the material for use. But if the set is delayed too long, some of this water is lost by evaporation, and some is removed from the field of action by rising to the top of the mold. There is also the possibility that organic colloidal retarders may coat some of the grains of calcined gypsum and prevent the water from reaching them. The net result is a loss of strength.

Shrinkage.—The tendency of retarded calcined gypsum to settle out before it hardens has a decided influence on the shrinkage of a casting. Unretarded calcined gypsum expands when it sets, a fact familiar to everyone. But if the same material is heavily retarded there is a shrinkage from the original volume of the plastic mixture. In this case you may get a harder, denser material but it would not be suitable as a casting plaster.

Heating.—Canals says that in orthopedic plasters the addition of alcohol to the mixture reduces the amount of heat given off by the setting of the plaster. From the "time-temperature" curves it will be noticed that the rise in curve due to heat of crystallization is slower for retarded mixtures than unretarded. In the above case, therefore, the temperature rise would be less due to the slower production of heat. By the addition

TABLE II

ACCELERATORS AND RETARDERS¹

	Time of set, minutes			
	22	25	26	24
10 gm. calcined gypsum + 7 ccm. H ₂ O				
10 gm. calcined gypsum + 7 ccm. 0.5 normal K ₂ SO ₄		3.5	4	
10 gm. calcined gypsum + 7 ccm. 0.5 normal KCl		4.5	4	
10 gm. calcined gypsum + 7 ccm. 0.5 normal KBr		4		
10 gm. calcined gypsum + 7 ccm. 0.5 normal KNO ₃		4	4.5	
10 gm. calcined gypsum + 7 ccm. 0.5 normal KClO ₃		5		
10 gm. calcined gypsum + 7 ccm. 0.5 normal KCNS		5		
10 gm. calcined gypsum + 7 ccm. 0.5 normal K ₂ Cr ₂ O ₇		5		
10 gm. calcined gypsum + 7 ccm. 0.25 molar K ₄ Fe(CN) ₆		6.5		
10 gm. calcined gypsum + 7 ccm. 0.25 normal K ₂ SO ₄ Al ₂ (SO ₄) ₃ 24H ₂ O		6.5	7	
10 gm. calcined gypsum + 7 ccm. 0.5 normal Na ₂ SO ₄		5.5		
10 gm. calcined gypsum + 7 ccm. 0.5 normal LiSO ₄		9		
10 gm. calcined gypsum + 7 ccm. 0.5 normal AgNO ₃		8		
10 gm. calcined gypsum + 7 ccm. 0.05 normal TiNO ₃		9		
10 gm. calcined gypsum + 7 ccm. 0.1 normal TiNO ₃		4		
10 gm. calcined gypsum + 7 ccm. 0.5 normal N(C ₂ H ₅) ₄ Cl		27		
10 gm. calcined gypsum + 7 ccm. 0.5 normal BaCl ₂		22		
10 gm. calcined gypsum + 7 ccm. 0.5 normal CaCl ₂		16		
10 gm. calcined gypsum + 7 ccm. 0.5 normal CdSO ₄		9		
10 gm. calcined gypsum + 7 ccm. 0.5 normal ZnSO ₄		12		
10 gm. calcined gypsum + 7 ccm. 0.5 normal CaSO ₄		11		
10 gm. calcined gypsum + 7 ccm. 0.5 normal NiSO ₄		13		
10 gm. calcined gypsum + 7 ccm. 0.5 normal CuSO ₄		9		
10 gm. calcined gypsum + 7 ccm. 0.5 normal CuCl ₂		14		
10 gm. calcined gypsum + 7 ccm. 0.5 normal Cu(NO ₃) ₂		15		
10 gm. calcined gypsum + 7 ccm. 0.5 normal SnCl ₂		11		
10 gm. calcined gypsum + 7 ccm. 0.5 normal Hg(CN) ₂		22		
10 gm. calcined gypsum + 7 ccm. 0.25 normal ThCl ₄		65		
10 gm. calcined gypsum + 7 ccm. 0.5 normal ThCl ₄		less than 3 hr.		
10 gm. calcined gypsum + 7 ccm. 0.5 normal HCl		12		
10 gm. calcined gypsum + 7 ccm. 0.5 normal H ₂ C ₂ O ₄		12		
10 gm. calcined gypsum + 7 ccm. 0.5 normal H ₂ SO ₄		11		
10 gm. calcined gypsum + 7 ccm. 0.5 normal CCl ₃ COOH		22		
10 gm. calcined gypsum + 7 ccm. 0.5 normal H ₂ C ₄ H ₄ O ₆		22		
10 gm. calcined gypsum + 7 ccm. 0.5 normal H ₃ BO ₃		28		
10 gm. calcined gypsum + 7 ccm. 0.125 normal CCl ₂ HCOOH		34		
10 gm. calcined gypsum + 7 ccm. 0.5 normal H ₃ PO ₄		32		
10 gm. calcined gypsum + 7 ccm. 0.5 normal CClH ₂ COOH		less than 40		
10 gm. calcined gypsum + 7 ccm. 0.5 normal CH ₃ COOH		150		
10 gm. calcined gypsum + 7 ccm. 0.5 normal C ₂ H ₅ COOH		180		
10 gm. calcined gypsum + 7 ccm. 0.5 normal C ^{OOH} .CH ₂ C(OH)		240-300		
10 gm. calcined gypsum + 4 ccm. 0.5 normal KCl		almost at once		
10 gm. calcined gypsum + 5 ccm. 0.5 normal KCl		2.5		
10 gm. calcined gypsum + 7 ccm. 0.5 normal KCl		4	4.5	
10 gm. calcined gypsum + 9 ccm. 0.5 normal KCl		4.5		
10 gm. calcined gypsum + 11 ccm. 0.5 normal KCl		5	5.5	

¹ J. Traube, *loc. cit.*

	Time of set, minutes
10 gm. calcined gypsum + 13 ccm. 0.5 normal KCl	6
10 gm. calcined gypsum + 15 ccm. 0.5 normal KCl	after 40 still not set
10 gm. calcined gypsum + 7 ccm. saturated KCl solution	12
10 gm. calcined gypsum + 7 ccm. 0.5 normal KCl solution	4.5
10 gm. calcined gypsum + 7 ccm. 0.25 normal KCl solution	5.5
10 gm. calcined gypsum + 7 ccm. 0.125 normal KCl solution	9
10 gm. calcined gypsum + 7 ccm. 0.0625 normal KCl solution	19
10 gm. calcined gypsum + 7 ccm. 2 normal KCNS	8 8.5
10 gm. calcined gypsum + 7 ccm. 1 normal KCNS	6
10 gm. calcined gypsum + 7 ccm. 0.5 normal KCNS	5
10 gm. calcined gypsum + 7 ccm. 0.25 normal KCNS	8
10 gm. calcined gypsum + 7 ccm. 0.125 normal KCNS	11
10 gm. calcined gypsum + 7 ccm. 0.0625 normal KCNS	13

TABLE III

ACCELERATORS AND RETARDERS¹

Name of admixture	Time of set, minutes		Name of admixture	Time of set, minutes	
	Plaster alone	Plaster plus one gm. of admixture		Plaster alone	Plaster plus one gm. of admixture
Potassium Salts			Acids		
K ₂ SO ₄	28	7	H ₂ SO ₄	28	11
KCl	26	7	HCl	28	18
KNO ₃	28	10	HNO ₃	28	19
KBr	26	9	H ₃ BO ₃	28	30
KI	26	13	Bases		
K ₂ CO ₃	28	22		28	12
K ₂ SiO ₃	29	39		28	14
				28	28
Sodium Salts			Ba(OH) ₂	28	29
NaCl	26	9	Other Inorganic Admixtures		
Na ₂ SO ₄	23	13	MgSO ₄	28	19
NaNO ₃	31	15	FeSO ₄	28	19
NaBr	26	14	CaSO ₄	28	22
NaI	26	15	CaO	28	30
Na ₂ HPO ₄	28	22	MnO ₂	28	27
Na ₂ CO ₃	28	30	SiO ₂	29	29
Na ₂ SiO ₃	29	95	BaS	30	30
Na ₂ B ₄ O ₇ · 10H ₂ O	28	300	Organic Substances		
Ammonium Salts			Sugar	{ 5 cc. H ₂ O plus	
(NH ₄) ₂ SO ₄	28	9		{ 5 cc. of syrup	
NH ₄ Cl	28	11	Glycerine	{ 55 cc. H ₂ O plus	
NH ₄ NO ₃	28	13		{ 5 cc. glycerine	
NH ₄ Br	28	16	Alcohol	{ 55 cc. H ₂ O plus	
NH ₄ I	28	17		{ 5 cc. alcohol	
			Soap (0.5 gm.)	25	19
			Soap (5 gm.)	25	10

¹ E. Canals, *Jour. Pharm. Chem.*, **14**, 33(1916).

TABLE IV
RESULTS OBTAINED AT BUREAU

Admixture	Amount of admixture	Calcined gypsum	Water	Temperature difference from time of mixing to end of final rise, in degrees	Time from mixing to end of final rise in time-tempera- ture curve, in minutes
		100	60	14	53
		100	70	13.5	59
KFFH	0.5 gm.	100	70	22	25
NaCl	0.5 gm.	100	70	19.5	38
NaCl	2.0 gm.	100	70	17.8	21
CaS	1 gm.	100	70	15.5	44
K ₂ SO ₄	0.5 gm.	100	70	17.7	50
K ₂ SO ₄	8 gm.	100	70	17.4	48
BaSO ₄	0.5 gm.	100	70	16.5	57
Ca(OH) ₂	0.5 gm.	100	70	17.5	49
CaCl ₂	0.5 gm.	100	70	17.7	81
CaCl ₂	2 gm.	100	70	18.2	51
CaCl ₂	8 gm.	100	70	20.9	43
Al ₂ (SO ₄) ₃	0.5 gm.	100	70	19.6	53
NH ₄ C ₂ H ₃ O ₂	0.5 gm.	100	70	17	64
Ca(C ₂ H ₃ O ₂) ₂	0.5 gm.	100	70	11.8	113
Ca(C ₂ H ₃ O ₂) ₂	1.0 gm.	100	70	8.8	200
Ca(C ₂ H ₃ O ₂) ₂	2.0 gm.	100	70	4.3	340
					still soft
H ₂ C ₂ O ₄	1 gm.	100	70	17.1	70
CH ₃ OH	5 ccm.	100	70	13.9	78
NaNH ₄ HPO ₄	0.5 gm.	100	70	17.4	102
NaNH ₄ HPO ₄	1 gm.	100	70	15.2	150
NaNH ₄ HPO ₄	2 gm.	100	70	20.8	86
NaNH ₄ HPO ₄	4 gm.	100	70	38.2	153
COOH.CH ₂ C(OH)	0.2 gm.	100	70	20.1	66
COOH.CH ₂ C(OH)	.5 gm.	100	70	11.2	165
COOH.CH ₂ C(OH)	.8 gm.	100	70	16.9	83
H ₂ C ₄ H ₄ O ₆	.1 gm.	100	70	15.9	84
H ₂ C ₄ H ₄ O ₆	.15 gm.	100	70	15.7	98
H ₂ C ₄ H ₄ O ₆	.3 gm.	100	70	18.7	91
H ₂ C ₄ H ₄ O ₆	4 gm.	100	70	16.3	59
Na ₂ B ₄ O ₇	0.5 gm.	100	70	16.5	93
Na ₂ B ₄ O ₇	1 gm.	100	70	17.7	222
Na ₂ B ₄ O ₇	2 gm.	100	70	41.1	262
Commercial retarder	0.066 gm.	100	70	14.9	92
Commercial retarder	.132 gm.	100	70	12.8	185
Commercial retarder	.198 gm.	100	70	8.1	254
Commercial retarder	.264 gm.	100	70	5.3	315
HPO ₃	.2 gm.	100	70	7.0	210
NaPO ₃	.1 gm.	100	70	9.4	232
Tannic acid	.1 gm.	100	70	7.4	281

Other accelerators: KCl, NH₄Cl, MgCl₂, NaNO₃, KNO₃, NH₄NO₃, KI, and CaSO₄. - 2H₂O.

of much alcohol and thereby a lower solubility of the calcium sulphate it seems natural there would be less heat from crystallization.

From a study of the "time-temperature" curve of calcined gypsum containing a small amount of soluble phosphate it will be noticed that there is a retardation of the beginning of crystallization and then very rapid crystallization. This was thought to be useful in work requiring such properties, as in the dental trade, and has since proved to be of value.

Effect of Additions on Hardened Product

The after effect on hardened plaster by the addition of accelerators and retarders is very important. Salts of sodium, magnesium, and iron have a tendency to cause efflorescence on the set material, no doubt due to the formation of their corresponding sulphates. This may not be serious where small quantities of such salts are used but is liable to give trouble if large quantities are present. Acids and acid salts cause a swelling and formation of large pores in the plaster. As practically all commercial calcined gypsums contain some calcium carbonate, the trouble probably is due to the liberation of the carbon dioxide.

NOTE: Acknowledgment is made to W. E. Emley, whose supervision of this work has contributed in a large measure to the value of results obtained.

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ORIGINAL PAPERS

AN ELECTRIC FURNACE TEMPERATURE REGULATOR¹

BY E. N. BUNTING

ABSTRACT

The theory and operation of an electric furnace temperature regulator of the Wheatstone bridge type are discussed. The regulator is suitable for use with rectified alternative current as well as for direct current, and will maintain a close constant furnace temperature.

It is often desirable to control temperature as accurately as possible for laboratory measurements at elevated temperatures, and the Wheatstone bridge type of regulator described by White and Adams² and H. S. Roberts³ has been successfully used. The regulator here described is also of this type, but differs from the others in the method of assuring constancy of temperature over long periods, and in that rectified alternating current, as well as direct current, can be used as the source of heat.

The main advantages of this type of regulator for small furnaces are the lack of an appreciable temperature lag between the heating element and the furnace chamber, the very close constant regulation obtainable, and the absence of any part of the regulator from the heating chamber.

Since the regulator holds the resistance of the heating element constant within narrow limits, the variations in temperature of this resistance de-

¹ Received Oct. 20, 1923.

² *Phys. Rev.*, **14**, 44-48 (1919).

³ *Jour. Wash. Acad. Sci.*, **11**, 401-409 (1921); *Jour. Opt. Soc. Amer.*, **6** [9], 965-977 (1922).

pend upon the value of the temperature coefficient of resistance of the heating wire used, the larger the coefficient, the closer the temperature regulation.

Figure 1 is a diagram of the regulator. It operates on the usual 110 volts with furnaces having a resistance, when hot, of 3 to 15 ohms, using a current of not over 20 amperes.

As the resistance and temperature of the heating wire in the furnace vary, the arm of the galvanometer, G , oscillates between its two contact points, causing the polarized relay, PR , to operate the main relay, MR , which alternately introduces and removes the resistance, R_1 , in the main supply line. With the correct setting of the rheostat the temperature within the furnace falls when R_1 is in the circuit, and rises when R_1 is short-circuited by the main relay. When operating, the fluctuations of temperature in the furnace occur from 20 to 80 times a minute, depending upon

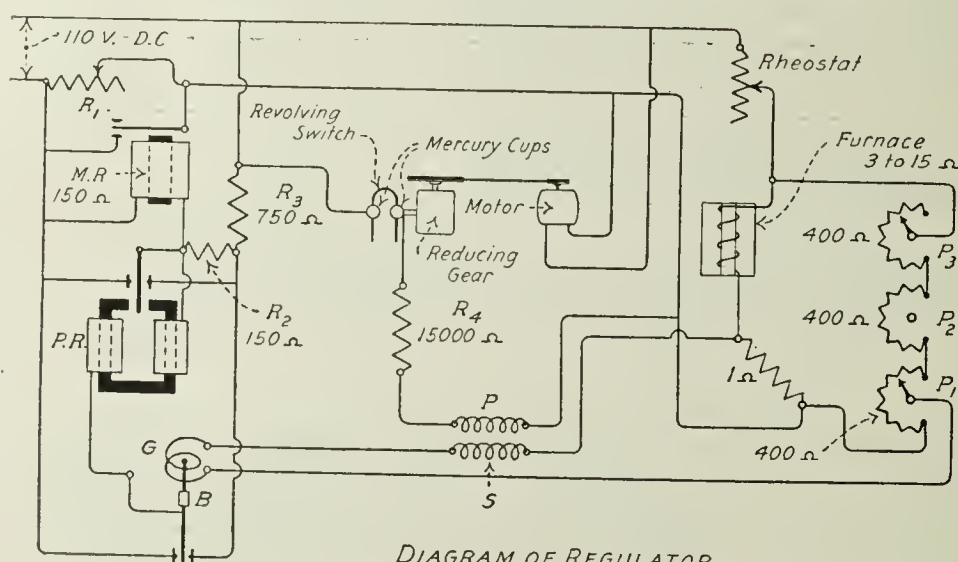


DIAGRAM OF REGULATOR

FIG. 1.

the setting of the rheostat and R_1 and upon the amount of separation of the contact points on the galvanometer.

If the galvanometer arm sticks to one of its contact points very long, the cycle of operations is interrupted and a large change in the furnace temperature occurs.

In order to prevent this sticking for more than a few seconds, the revolving switch as it passes through the mercury cups sends a small current through the primary winding, P , of a small bell transformer which induces a current through the secondary, S , and through the galvanometer coils. A momentary kick is thus given to the arm, causing it to break loose from the contact point, or to make contact should it have failed to do so as usual.

As a heating element any metal or alloy with not too small a temperature coefficient of resistance can be used, provided it does not oxidize or corrode very much at the temperature required. Iron wire can be used up to 300°C , nickel to 500° , and Monel metal to 750° . The alloy "alumel," can be used as high as 900° , but as its temperature coefficient at $800\text{--}900^{\circ}$ is only .0007, the regulation may not be as close as desired. The wire or ribbon used should always be covered with a layer of alundum cement or other refractory material in order to reduce oxidation or vaporization. It is not advisable to use platinum much above 1500° for long periods of

time, as vaporization of the wire then becomes quite appreciable. For temperatures above 1600° , either iridium, molybdenum or tungsten can be used in specially designed furnaces.

The other quarter of the bridge in series with the furnace is a one ohm resistance made from a small temperature coefficient alloy, such as constantan, ideal, advance. Nichrome or chromel may also be used if very close regulation is not desired. The wire used for this resistance should also be large enough to carry the current used without becoming much hotter than 100° . All connections on this side of the bridge should be made either with heavy copper wire or with one of the alloys mentioned. The other half of the bridge consists of three 400-ohm variable resistances, P_1 , P_2 , and P_3 , sometimes called potentiometers when used in radio receiving sets. These resistances need not be made from small temperature coefficient alloys, since the temperature is uniform throughout this side of the bridge. If the wire is scraped where the sliding contact is made, little difficulty should be experienced with changing resistance at the contact point.

The galvanometer is a modified portable Leeds and Northrup. The original pointer arm was removed and a piece of Pt-Rh thermocouple wire $3/4$ -inch in length, flattened at one end, substituted. This wire was fastened to the stub of the original pointer by means of a small hollow cylinder of bakelite, B , into which the wires were sealed. Two contact points of the same wire were added and a loop of No. 40 copper wire six inches long run from the pointer arm to the fifth binding post, situated directly over the suspension wire. One millivolt applied to the coil terminals of the modified galvanometer produces a deflection of the pointer arm of about one millimeter. The contact points are six millimeters apart so that the arm makes contact at ± 3 millivolts. Any similar instrument, such as the Weston "Model 30, five binding post galvanometer" used by Roberts, will operate successfully.

The polarized relay, PR , is one of the usual telegraph type of 2000 ohms or more, resistance. With this resistance and those given for R_2 , R_3 and MR , the current through the contact points of the galvanometer is reduced to approximately 8 milliamperes, at which value practically no corroding or pitting of the contacts occurs.

When not more than a 12-ampere current is used, an ordinary telegraph relay will serve as the main relay, MR , without undue sparking. After the alloy contacts of this relay wear out they should be replaced with molybdenum contacts, which will give much longer service. For currents of 12 to 20 amperes, the H_2 atmosphere mercury relay described by G. Barr¹ is recommended. This relay requires no attention and is also preferable for the lower amperage.

¹ *Proc. Phys. Soc. (London)*, 33, 53-56 (1920).

The value of the resistance, R_1 , should be adjusted to give a variation of about 20% in the current through the furnace. The resistance, R_2 , should equal that of the main relay, and R_3 should have a resistance such that sufficient current will flow to operate the main relay and the polarized relay without sending over 10 milliamperes through the galvanometer contacts.

The bell transformer is one of the ordinary type stepping down 110 volts to 12 volts.

When R_4 has approximately 15000 ohms resistance, the galvanometer arm receives a sufficiently violent deflection to prevent sticking. This resistance was obtained by soldering 3 RCA .05 megohm grid leaks in parallel.

The revolving switch consists of a U-shaped piece of nichrome wire sealed onto the slow motion shaft of the reducing gear. At each revolution of the reducing gear shaft, this wire passes through the surface of two mercury wells, thus completing a circuit through the primary of the bell transformer. The switch rotates about six times a minute. Since very little work is done by the gear, a $1/20$ -h. p. motor, driving the gear by a small leather belt, is sufficient. The reducing gear runs in vaseline and is practically noiseless.

The following formula quite closely gives the variation in temperature, ΔT , of the heating element during each cycle of the regulator

$$\Delta T = \frac{2v}{\left[\frac{r_1 + \alpha r_0}{r_2 + r_1 + \alpha r_0} - \frac{r_1}{r_2 + r_1} \right] V}$$

where v = voltage required to close galvanometer contact (.003)

r_0 = resistance of heating element at 0°C (1Ω)

r_1 = resistance of hot heating element at temp. T (5Ω)

r_2 = resistance of bridge wire in series with furnace (1Ω)

α = temp. coeff. of resistance of heating element (.0039)

V = voltage drop across ends of bridge (60 at 1000°)

The values given in the parentheses apply to the furnace and regulator used in the laboratory here for which $\Delta T = .9^\circ$ or $\pm .45^\circ$ from the mean temperature. As the galvanometer arm occasionally sticks for a few seconds, the temperature of the heating element may occasionally vary a few times this amount. Since the heat capacity of the furnace walls and insulation is several times that of the heating element, the temperature variation at a definite spot within the furnace chamber is much less than the temperature variation in the heating wire, being at most only a few tenths of a degree.

As long as the physical properties and dimensions of the heating element do not change, the same setting on the bridge will always hold the furnace

to the same temperature, provided no large change in the room temperature occurs. As the heating wire oxidizes or vaporizes, the bridge setting, in order to maintain constancy of temperature, must be changed to compensate for the change in the wire. When a platinum heating wire is used, a constant temperature of 1100°C within the furnace can be held for days, without changing the bridge setting. Above 1200° the furnace will drop in temperature slowly and an occasional adjustment of the bridge setting is necessary to keep the temperature constant. At 1400° this drop in temperature amounts to 10° or more a day, due principally to the vaporization of the platinum decreasing the cross-section of the wire. Since the regulator maintains the resistance of the wire almost constant, it is evident that as the cross-section of the wire becomes smaller, the lower the temperature necessary to keep it at a definite resistance.

DEPARTMENT OF CERAMIC ENGINEERING
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A RECENT INSTALLATION OF A HARROP TUNNEL KILN¹

BY GORDON P. GAVIN AND FRANK M. HARTFORD

ABSTRACT

The proper firing treatment for producing a large capacity of sanitary ware requires a car tunnel kiln of exceptional flexibility. A recent installation of a tunnel kiln, 360 feet 10¹/₄ inches long, operating at cone 10 flat, is producing 540 pieces of bisque sanitary ware per day and has a firing cycle of 67¹/₂ hours.

Oil is depended on entirely for fuel, there being no auxiliary gas or coal burning equipment.

Humidity driers are used in connection with this tunnel kiln and derive all their heat from the waste heat of the kiln.

Introduction

Slow Uniform Heating Necessary.—It has been demonstrated that in order to prevent heating-up cracks in sanitary ware, it is necessary to bring the piece up to red heat uniformly and comparatively slowly, and then raise the temperature quite rapidly to the maturing point. While it has been comparatively easy to secure and maintain a heating-up curve, or temperature gradient, having the same rate of temperature increase for every hour during the heating-up period, it has been a much more difficult matter to bring all the saggars on a car up to heat in the afore-mentioned desired manner, in which the temperature rise during the first part of the heating-up period is slow and then is sharply increased after the ware has come to a

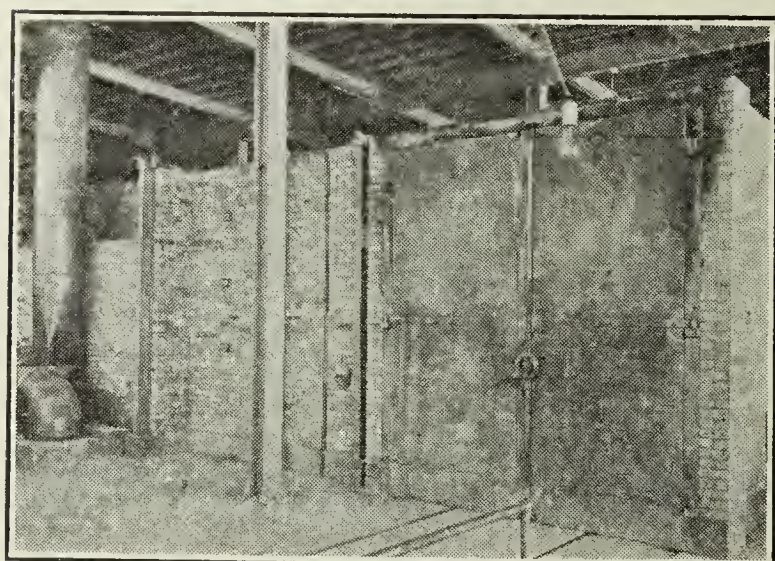


FIG. 1.—Charging end of kiln showing side entrance and draft fan.

red heat; and to do this with a tunnel kiln firing a large tonnage of ware.

Sanitary ware requires a kiln of great flexibility in order to secure and maintain the desired temperature gradient while producing a practical tonnage of number one ware. The kiln capacity—the amount of ware fired in twenty-four hours—must be sufficiently large to make the process worth while and to justify the cost of the installation. In order that a car tunnel kiln be practical, it must have a large capacity, require but little for maintenance, be simple yet efficient in design, and sturdily built. The mechanical members must be few and of excellent materials and design. Mechanical trouble should never be of such frequency as to be harassing to the operators.

¹ Presented before the Heavy Clay Products Division, Pittsburgh Meeting, Feb., 1923.

Description of Kiln

Size.—The car tunnel kiln recently built for the Kalamazoo Sanitary Manufacturing Company is 360 feet $10\frac{1}{4}$ inches long, is direct-fired, and is using 34–36° Baumé gas oil as fuel. The kiln has a placing width of 5 feet 4 inches and a placing height of 5 feet 6 inches.

Capacity.—This kiln contains forty-five cars under actual firing conditions. Although the kiln will operate at a capacity of 648 pieces of fired bisque sanitary ware per day, the plant production has not required that it operate at a greater capacity than 540 pieces per day. It has been operated at this latter schedule for approximately six months, and since the initial heating-up of the kiln until the time of writing this article, its performance has not been delayed for more than an hour.

Time Schedule.—It will be observed (Fig. 3), that almost one-half the time of the entire firing cycle is used in bringing the ware up to a good red heat, and approximately one-sixth of the firing cycle is devoted to raising the temperature of the ware from that point to the maturing heat of cone 10 flat. After the ware is matured the drop in temperature for a time is rapid, only one-seventh of the firing cycle being required to lower the temperature to about 1200°F. The remainder of the time in the kiln is used to bring the ware down to the discharging temperature indicated.

There are five furnaces on each side of the kiln or ten furnaces in all. However, only eight of these furnaces (four on each side) are under fire. A highly oxidizing atmosphere is maintained in the tunnel at all times. The furnaces are operated with a slightly increasing temperature in each pair of furnaces, the pair of furnaces farthest from the charging end of the kiln being the hottest and finishing off the ware at cone 10 flat.

Fuel Oil System.—The 34 to 36° Baumé gas oil is burned through low-pressure Sta-Kleen burners, the oil being supplied to the burners under sixty pounds pressure. The air used for primary air of combustion is

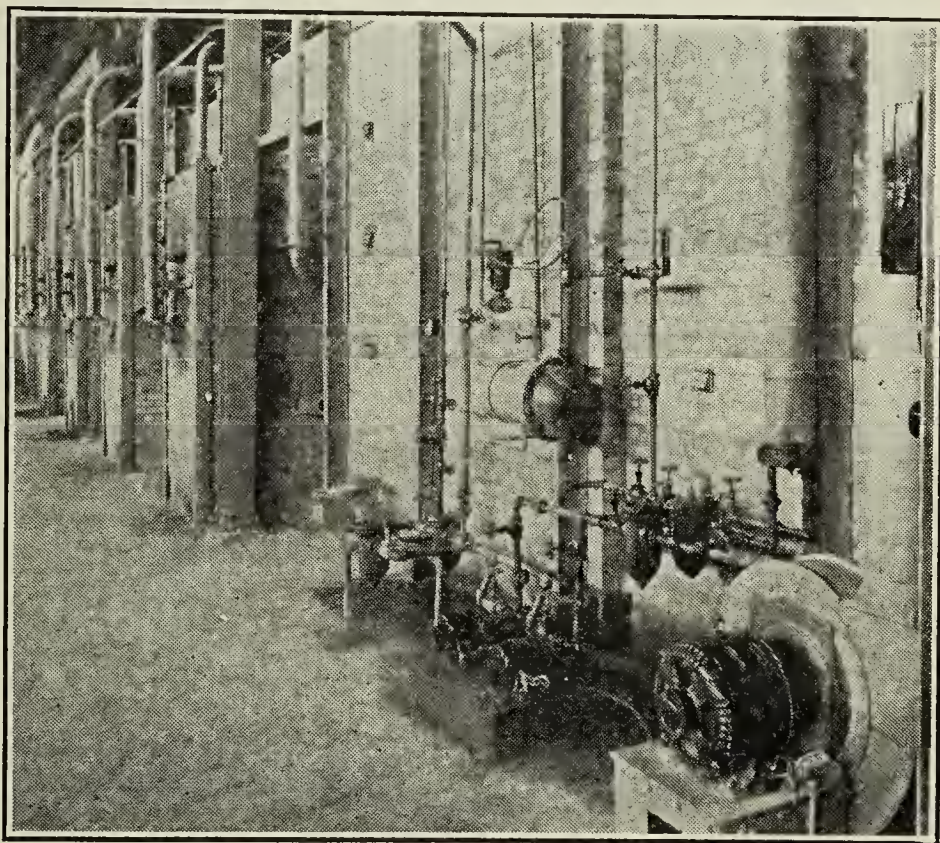


FIG. 2.—Furnace section showing fuel oil burning equipment.

fed through the burner around the oil at a pressure of 13 ounces. Approximately 1100 gallons of oil are consumed per 24 hours, oil costing about seven cents per gallon at the burner. Each unit is composed of a $\frac{3}{8}$ -inch Viking oil pump, directly connected to a $\frac{1}{4}$ -h. p. motor, with the necessary valves and strainers. Normally, only one unit is in operation and the other unit is reserved for emergency use. The pumps are so connected that either one or both may be used to maintain the oil at sixty-pound pressure.

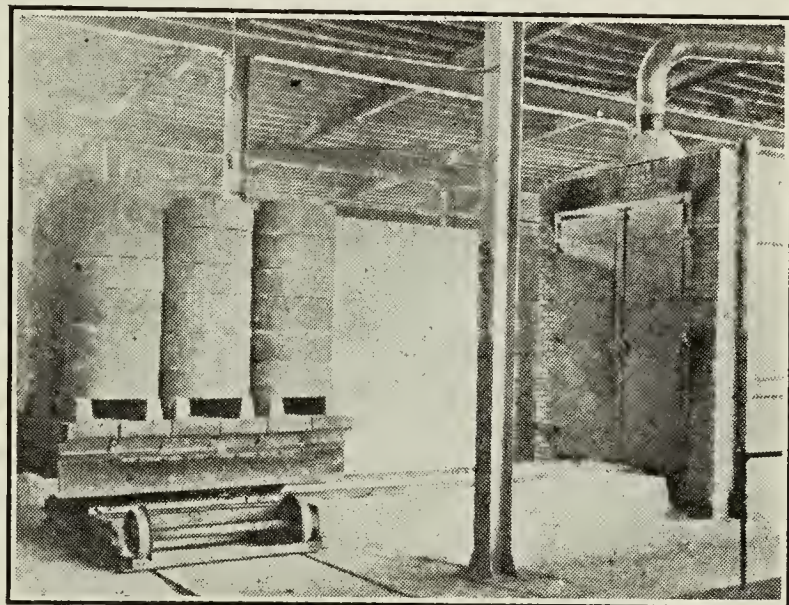


FIG. 4.—Discharging end of kiln showing car of fired ware.

Circulatory Fuel Oil System.—The fuel oil system is circulatory, with the return line emptying into the oil suction line through a pressure valve. This arrangement eliminates considerable load on the pumps, which would occur should the return line empty back into the oil reservoir and the excess oil again be lifted several feet. The piping system is also simplified by connecting the return line in this manner. The oil burning system also includes a 5-h. p. motor driving a pressure fan at 3400 r.p.m. and supplying air at the burner at upwards of 13 ounces static pressure.

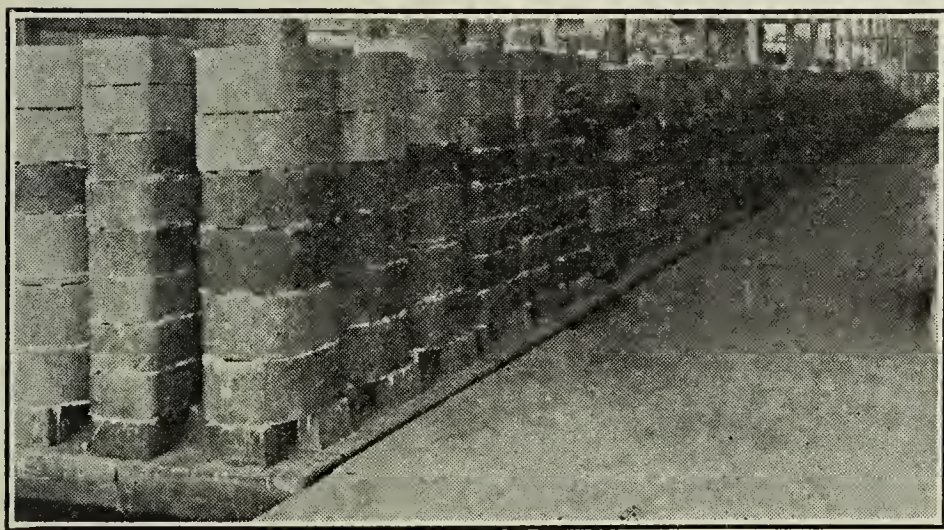


FIG. 5.—Return track, cars ready for charging into kiln.

Operation of Kiln.—

The operation of the kiln is as follows: The loaded car is carried on the transfer car, at the charging end of the kiln, into the charging vestibule through doors on the side. A hydraulic pusher of 10-ton capacity (actual push being 8462 pounds) pushes the kiln car off

the transfer car and in doing so gradually moves the whole train of cars in the kiln forward one car-length. At the time of charging the next car this same procedure takes place and the cars move slowly through the kiln, receiving as they advance the firing treatment previously described.

Method of Discharging Cars.—After a car is discharged from the kiln, it is pushed on to another transfer car at the discharging end of the kiln,

is carried over to an elevator and lowered to the return track level. The return track is at a lower elevation than the kiln track so that the bottom of the ware setting is level with the factory floor. This makes for ease in placing and drawing the ware. All the placing and drawing is done on this return track and when the trucks are again loaded ready for the kiln, they are raised to kiln track level by means of another elevator at the end of the return track opposite the first elevator mentioned and are charged into the kiln as described above.

The elevators, which are placed one at each end of the return track, are of the four-screw mechanical type much used in Michigan planing mills. There is a screw standard at each corner of the platform, the screws being arranged in pairs and each pair connected by means of a shaft with a pinion gear on each end. These pinion gears mesh with a lifting ring gear which runs on the screw standards. The two shafts are driven by one motor connected to same by silent chain drives. These elevators, carrying a load of about six tons, have proved very satisfactory.

Other Equipment.—In addition to the fuel oil burning system, the mechanical equipment on the kiln includes one 10-ton oil-gear hydraulic car pusher driven by a $\frac{3}{4}$ -h. p. motor, one American Blower Company draft fan and one American Blower Company air supply fan, each of which is directly connected to a $7\frac{1}{2}$ -h. p. motor.

Waste Heat Utilized

Another advanced application of time-saving equipment in connection with this kiln is the installation of humidity driers, the entire heat for same being supplied by the waste heat from the tunnel kiln. The kiln furnishes enough waste heat to the humidity drier to dry all the ware fired in the kiln. By means of this combination equipment, ware which formerly required twenty-one days to dry is now dried more thoroughly in eighteen hours.

Uniform Firing of Ware

This car tunnel kiln has proved very successful in firing the ware to a uniform cone 10 burn all over the car setting and with the losses in the kiln far below the normal kiln losses in a periodic kiln plant. This factory had two tunnel kilns each about three hundred and sixty feet long. Bisque ware was fired in the first tunnel and glost ware in the second. Glost ware is now fired in the two old tunnel kilns and all the bisque ware, necessary to keep the two glost kilns operating at full capacity, is fired in the new kiln.

THE USE OF WOOD IN GAS PRODUCERS

BY C. SAXTON¹

ABSTRACT

The possibility of using wood as source of gas supply for melting of glass and firing of clay products is suggested. Comparative results actually obtained with same plant using coal and wood are given.

Introduction

In determining the location of a new factory, one of the principal points usually considered is an adequate available supply of fuel at an economic price. For the manufacture of articles requiring high temperatures, this question becomes of particular importance because fuel usually is one of the largest items in production cost.

This very naturally is a great influence in limiting the areas in which ceramic factories can economically be operated, as otherwise the transport charges on the fuel may be prohibitive.

The fuels usually used for glass melting or clay firing are coal, oil or gas. From his own experience recently, however, the writer would like to suggest that it is possible to add another fuel, namely wood, to the three already mentioned, and thus in some instances enable factories to be operated successfully in areas which, while possessing many other desirable features, have so far been ruled out of consideration on account of fuel supply.

Wood in Gas Producers

The use of wood for the production of gas is by no means new, but the gas so produced has usually been used for operating gas engines. During the war many municipal gas works were compelled to use wood and sawdust.

It is essential, when using the gas from wood for either engine work or for illumination purposes, to extract the tar, whereas when it is to be employed in furnaces, extraction of tar is not only not essential, but in some cases it would really be a disadvantage.

Just after the Armistice the writer was operating a glass plant in France when it was impossible to obtain suitable French coal at any price. American and English gas coal were obtainable but at a cost so prohibitive it was a question of either finding an efficient substitute or shutting down the plant.

Oil was, of course, at first considered but its price was steadily rising, in fact did rise from 330 francs (\$22) to 900 francs (\$60) per ton.

It was desired that the one tank furnace be kept in operation, which fed two (old type) six arm Owens machines.

¹ A.M.I.E.E., M. Iron & Steel Inst. Received Oct. 8, 1923.

The gas plant consisted of two ten-foot gas producers of the hand-poked, water-jacketed type, provided with revolving grates. The blast was furnished by a motor driven fan, steam being admitted directly into the air pit under the dome of the grates.

These producers made the gas required for the main melting furnace, the two revolving pots and also two 7 by 75-foot leers. The melting furnace was only working at about one-half its capacity. It was big enough to melt 38–40 tons per day, whereas the machines were only pulling out about 20 tons (making small bottles). The labor available was anything but good, particularly the gas makers, who had a marked disinclination to use the poker, consequently there were times when the supply of gas was deficient even when using good coal.

Owing to the general shortage of coal, wood was being used quite generally in the surrounding districts for steam so there was not much difficulty in getting a stock of three or four hundred tons. Having heard that wood had been used with some success in an Italian glass works during the war, it was decided to give it a trial.

The first trials were half-hearted, as the wood was used on one producer only, in the proportion of about 20% wood and 80% coal. This percentage was gradually increased to 80% wood and 20% coal, with satisfactory results and finally all wood was used on one producer. The whole load on the producers was then transferred to the one using wood, by gradually shutting off the blast to the other one. At the end of 24 hours it was found that all the gas required was being supplied easily by the gasification of the wood; and the other producer was shut down. For a period of approximately nine months one producer gasifying wood was doing the same work and doing it better than the two had done on coal.

Kinds of Wood.—The wood used was principally white oak and evergreen or live oak, but at times a quantity of beech and elm were received, and in general it may be said that the best results were obtained with the hard woods.

State of Wood.—The wood was used in all stages of dryness, ranging from two days after cutting, with the leaves still green and fresh, to wood that had been cut for seven or eight months, which owing to the climatic conditions could be considered as being reasonably dry.

Sizes of Wood.—The sizes varied from small twigs of about $\frac{3}{4}$ -inch diameter up to pieces 6 inches diameter, this being the maximum diameter accepted, the majority being in the neighborhood of three to four inches. Twelve inches in length was the maximum allowed to go on to the charging platform. These dimensions (6 inches x 12 inches) were decided in a purely arbitrary manner, as they happened to be the largest which it was considered would pass through the charging hopper without risk of jamming.

The cut pieces were taken up on to the charging platform in hoppers,

count being kept of the number going up and the weight per hopper was checked fairly frequently. All the sawdust, bits of twigs and bark and general waste was kept until the weekly "burning out" period. It was then fed into the producers during the time that the blast was off.

Operation of Producers.—No structural alterations were made to the producer but a thicker fuel bed was maintained. No steam was used at all in the air blast and the grate was kept rotating continuously at its slowest speed.

Owing to the impossibility of poking efficiently fears were entertained at first that there would be a tendency to develop blow holes in the fuel bed, but by keeping the grate continuously on the move, no trouble whatever was experienced.

The gas makers now had practically nothing to do but charge the hopper. They would persist in filling the producer almost up to the gas outlet and then having a long rest, a practice that was not tolerable. As a check on the frequency with which the producer was charged a sensitive recording pressure and draft gage with a center zero was connected to the gas outlet. Since each time the "bell" of the charging hopper was lowered there was a momentary recordable drop in pressure it was possible to obtain an exact control record of the number of charges made and the intervals between successive charges.

Ash.—As wood contains at the maximum approximately 1.5% ash, this question did not present any additional difficulties, but on the contrary, there was a good demand locally for the ash as an artificial manure. The ash was removed in the form of a greyish white sludge, absolutely free from any combustible material.

In order to ascertain when it was necessary to put in the plough to remove the ash, a U-tube was fixed with one leg connected to the air pit under the grate and the other in the gas outlet, so that the difference in the height of water in the two legs was a measure of the resistance of the fuel bed to the passage of the blast. When this rose above a predetermined figure the ash was removed.

It occasionally happened that too much ash was removed, but this was immediately evident by charcoal floating in the water in the ash pan. This charcoal was removed, dried and used in the batch.

Tar.—When using wood the question of tar trouble immediately presents itself but in the present installation no trouble at all was experienced owing to the flues being comparatively short and therefore hot, thus not giving the tar vapors an opportunity to condense.

By "burning out" thoroughly each week-end, even the two leers never caused any trouble in operation.

Economies of Wood in Gas Producers

FUEL CONSUMPTION

	Coal	Wood
Glass melted per day.....	20 tons	20 tons
Fuel used per day.....	26 tons	39 tons
Cost per ton delivered on to producer platform	360 francs	100 francs
Fuel cost per ton of glass.....	468 francs	195 francs

When considering the above figures it must be borne in mind that the fuel consumption includes that required for the two revolving pots and two leers as well as the actual melting tank, and also that the tank was only working at half its capacity which naturally increases the weight of fuel per ton of glass.

After the plant had been working some time on wood there was a steady reduction in the price of fuel and the comparative figures were then:—

	Coal	Wood
Glass melted per day.....	20 tons	20 tons
Fuel used.....	26 tons	39 tons
Cost per ton on charging platform.....	150 francs	60 francs
Fuel cost per ton of glass.....	195 francs	117 francs

Steam.—These results were naturally very gratifying but in addition there were several other economies and advantages. Taking first of all the steam item: very few of the smaller glass works appear to realize what it costs to generate the steam required for a modern producer using coal, but on this item alone there was a saving of 210 francs per day.

Labor.—By the replacement of gasmakers by laborers, and the shutting down of one producer an economy of 305 francs per day was made in labor costs.

Power.—The power required to rotate the grate was reduced from 6 h. p. to 2.7 h. p.

Taking into consideration fuel, steam and labor the relative costs per ton of glass were:—

Coal at 150 francs per ton
226.3 francs

Wood at 60 francs per ton
123.00 francs

Other Advantages

Several advantages to which it is extremely difficult to attach a definite financial value were obtained, among which may be mentioned having a standby producer in the event of anything unforeseen happening to the one in operation, and also the fact that everything worked without trouble or hitch usually associated with a small producer installation.

During the whole of the period that this plant was operating on wood gas, there was never a moment lost due to lack of gas or heat, or bad metal.

Conclusion

It will be easily seen that under certain circumstances the possibility of using wood as a source of gas for glass melting may become a proposition worthy of consideration, as there is not the slightest doubt that if a plant were to be designed and built with this object, it would easily be possible to improve upon the figures given. In the case just considered, all the arrangements were such that at the most they could only be termed make-shift in character, and in consequence not as efficient as could be desired.

C. SAXTON

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SOME VITAL FACTORS IN REDUCTION OF FUEL COSTS¹

By W. C. BUELL, JR.

Introduction

It is a fallacy to suppose that any great fuel economy will come from the introduction of any particular fuel system. The first step in fuel saving lies in the detail design of the furnace and its fire box or burner setting, the design of the arch, flues, stack and the coördination of these with the fuel supplying mechanism of the equipment. A considerable economy can more probably be secured from well designed and properly built furnaces than from changes in fuel system. The second possible source of fuel conservation comes from the re-use of waste heat.

In heating operations at high temperatures, the gases of combustion become waste at temperatures greater than that of the substance being heated. In a glass tank furnace, and in the conventional down-draft kiln, the temperature of the products are in the neighborhood of 2500°F. In both of these, the gases of combustion leave the furnace at temperatures above this. Assuming that the gases leave at 2600°F under complete combustion the gases will contain about 65% of all the energy originally in the fuel or to put it in terms of dollars and cents, of \$1.00 worth of fuel, 65 cents worth enters the flue. The 65%, of course, is only encountered at high temperature and if instead of 2500°F the gases leave the furnace at 1200°F, they will contain only about 27% of the total original fuel. The above range of waste gas temperature is roughly that encountered in the ceramic industry.

Salvaging of Waste Heat

Waste Heat Boiler.—There are three general methods of salvaging waste heat. Possibly the easiest method is using the waste heat to generate steam, and if large quantities of steam are used, very substantial economies may accrue from the use of waste heat boilers.

Drying.—A second method of salvaging this waste heat is to use it in drying processes. The brick industry has long made a practice of utilizing a small part of waste heat for the drying.

Recuperator.—The third method consists of returning a part of the sensible heat in the waste gases to the furnace proper by a regenerative or recuperative device, as in case of the glass tank and pot furnaces, and in the modern tunnel kiln.

Types of Recuperators

Recuperators are of two general types, those made with clay and those with metallic elements.

¹ Presented before the Glass Division, Pittsburgh Meeting, Feb., 1923.

Clay Brick or Tile.—The clay type is open to four rather severe criticisms: (1) the structure is fragile; (2) it is hard to maintain in a proper degree of tightness due to loosening of the cement; (3) the coefficient of heat transfer, as compared to metallic elements, is extremely low, necessitating a much larger structure to secure equivalent transfers; and (4) the initial cost is relatively great.

Metal.—Tile or other refractory material must be used in recuperators or regenerators, unless it is possible to maintain the temperature of the metallic elements at temperatures under 1800°F . This does not mean that clay devices must be used if the gas temperatures are above 1800°F . With the furnace gases entering the recuperator at 2500°F and the air from the recuperator heated to 1100°F , the temperature of the recuperator elements will approximate the mean of the gas and air temperatures; hence the metallic air containing elements would be approximately 1700°F .

Calorized Tubes.—Metal elements may be calorized to prevent burning out at high temperatures. In this process aluminum is driven into the metal so as to form aluminum alloy surfaces. These surfaces withstand the action of furnace gases at high temperatures and have a high rate of thermal conductivity at all times.

Economies of Metal Recuperators

Metallic recuperators can usually be applied to existing furnaces at quite a nominal cost and will bring about marked economies in operating cost and time, and an improved product.

It is often possible with metallic tubes to produce over-all savings in excess of 25%. It is possible to build a recuperator to return practically any percentage of the heat in the waste gases, although it has seldom been found profitable to carry recuperator design to a point of greater than 30 to 50% efficiency depending upon the temperature. The higher the operating temperatures, the more economical will the recuperation be.

Recuperation in Ceramic Plants

There are opportunities in the ceramic industry for fuel conserving equipment. Attention is particularly called to the "day tanks" and leers of the glass industry and the conventional down-draft kiln of the brick industry. There can, however, be no standard equipment designed for the purposes of recuperation, for each and every piece of fuel consuming apparatus is an individual problem and must be considered as such.

The pertinent question is what over-all fuel saving might be anticipated by the use of recuperators. No general rules will cover all cases, for a great number of factors, many of them individual to each shop, enter into the final result. It can safely be said that recuperation will not pay unless a direct fuel saving of 20% may be secured. The savings have been above

50%. It naturally follows that the better the shop practice the smaller will be the fuel saving and the poorer the present shop practice the greater will be the saving.

A large saving from the use of recuperators is in the quantity of fuel used. The lower amount of fuel per quantity of product will usually give an over-all saving much greater in proportion than the percentage of heat returned by recuperation. The flame temperature of the fuel is higher and a more rapid combustion reaction is secured and a higher temperature differential within the furnace is maintained. As heat transfer varies directly as the fourth power of the increase, even a slightly higher flame temperature will enormously speed the operation with the result that the time factor is materially reduced.

The time is now with us when fuel costs must be reduced both from the point of earnings and the conservation of the fuel resources of the country.

BUELL, SCHEIB, MUELLER, INC.
PITTSBURGH, PA.

Discussion

W. B. CHAPMAN:—Mr. Buell's statement that usually 27% of the fuel can be saved by preheating the air is conservative, provided the air is sufficiently heated.

Not long ago we went over the figures of eight typical furnaces we have built and the average saving of fuel due to high temperature recuperation, as compared with little or no recuperation, was slightly over 30%. Therefore, it is reasonable to accept the 27% mentioned by Mr. Buell as a fair estimate. It seems to be the custom in this country to rebuild old furnaces, rather than build new ones. The patent hollow tile method of recuperation which we employ does not lend itself very readily to the remodeling of old furnaces: therefore the use of calorized pipe which is well adapted to remodeling old furnaces will open a large field and supply a real need. For every new furnace built there probably are opportunities to rebuild or remodel ten old ones. I believe, however, that the higher temperature operations are not suitable for calorized metal recuperators—I think Mr. Buell mentioned 1800° as possible.

With plain cast iron recuperators of the old-fashioned kind the air was preheated usually to but 400°F, and even this small amount of preheat was found well worth while. Mr. Buell claims that calorized, mild steel pipes will stand a temperature of 1800° and he mentions having preheated the air to 1400°F in a recuperator made of calorized pipes. This is a big gain over old practice with cast iron pipes where 700°F is the highest limit and 400°F the usual working practice.

Furnaces often get out of control and the temperature of the spent gases often rises far beyond what it should be, therefore, even if calorized steel tubes can be heated twice as high as is safe with plain cast iron there

still is much more to be desired. For in all high temperature furnaces the temperature of the spent gases is well beyond the limit of calorized steel tubes. Therefore, although calorized steel tubes may be used to advantage in rebuilding an old furnace and are exceptionally well suited for low temperature furnaces such as heat treating operations, when it comes to the most efficient and safest recuperator for high temperature furnaces there is nothing better for a recuperator than special hollow tile made of high grade refractory material. With a properly designed recuperator made of good refractory clay we have found it possible to preheat the air to 1950°F and keep it up continuously without any risk to the life of the recuperator. The temperature of the spent gases on the other side of the tile in this recuperator is about 2350°F and the average temperature of the tile itself is therefore 2150°F.

The higher you heat the air the greater the theoretical saving and in practice the saving is found to be even greater than in theory, for the more you preheat the air the less excess air you need and the better it combines with the fuel. Therefore, if you are burning oil, the higher the air is preheated the less you need to be careful about atomizing, and if you are burning powdered coal the higher the air is preheated the less finely the coal has to be pulverized. This reduces the cost of pulverizing and also insures more complete combustion.

With oil fuel it has been thought necessary to use a certain amount of air or steam to spray it into the furnace. This is no longer necessary. There are a number of devices working successfully. I know of an extreme case in a Russian design of open hearth furnace where fuel oil is merely dripped into the draft of highly preheated air at several different points across the air port—no attempt being made at spraying. In France our associates installed an open hearth furnace of this type a few years ago and although everyone was rather skeptical at first the owners of the steel works after having one in operation for some time put in two more. In this country oil burning without steam or air under pressure was first developed by one of the glass manufacturers present. With this new and improved method all of the air can be preheated with its consequent advantages and economy.

I believe that there is a great improvement coming in this country in fuel saving and furnace operation generally, not only in the glass industry but in other lines as well, due to the general recognition of the need of doing much more preheating of the air to high temperatures than heretofore.

A MEMBER:—A saving of 30% is conservative. It runs higher than that in a great many instances. One point that impressed me strongly about high temperature recuperation was the increased furnace capacity and efficiency made possible by the increased differential between the flame temperature and the material heated.

A SKIAGRAPHIC STUDY OF FABRICATED GLASS ARTICLES¹

BY C. D. SPENCER AND A. E. BADGER

ABSTRACT

A method is described whereby defective construction may be determined in fabricated glass articles. The principle is the same as that of the immersion method of grading optical glass. The glass object is immersed in a fluid whose refractive index for some monochromatic source of illumination is approximately equal to that of the article. Under these conditions it is possible to observe defects in the structure of complicated glass objects.

Introduction

The production of glass articles of any form entails various percentages

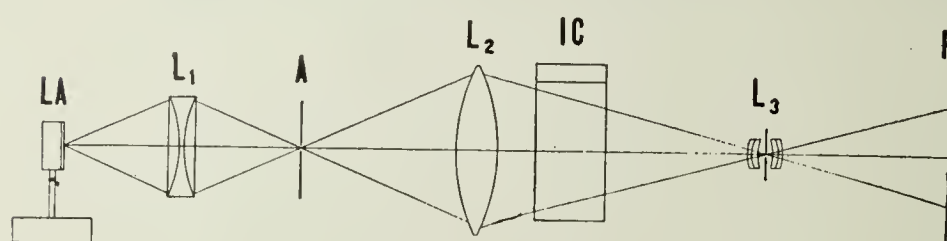


FIG. 1.

of breakage, depending on the complexity of the resulting product. The cause of breakage in many instances is a defect of construction. The ob-

ject of this paper is to describe a simple method for determining defective construction in fabricated glass articles.

The Method Described.—The principle of the method is illustrated in Fig. 1. This is the usual set-up for observing and photographing striae in rough chunks of glass. It is a simplification of the immersion method used in grading optical glass. The source of monochromatic light, LA, is a mercury arc. L₁ is a condensing lens which forms an image of the source of light on the small circular aperture, A. By means of a lens, L₂, either parallel or slightly convergent light may be passed through the immersion cell, IC. If the object is to be photographed, a lens, L₃, is used to form an image in the plane, P. The lens, L₃, may be either the lens of the eye, for visual observation, or the objective of a camera. For visual examination mercury green light is used for illumination. If it is desired to record the image photographically, lantern slide plates may be used, but since they are relatively insensitive to green light mercury blue light should be substituted. The refractive index of

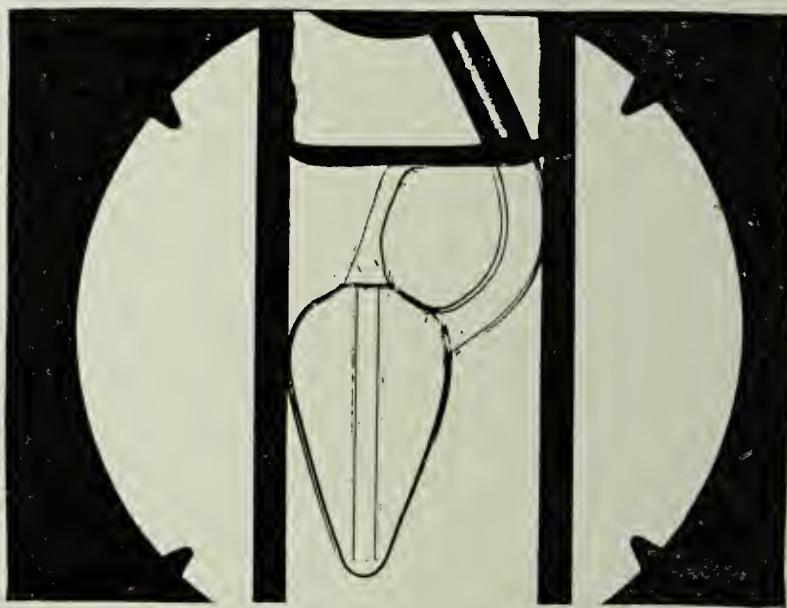


FIG. 2.

¹ Received Sept. 29, 1923.

the immersion fluid is then adjusted until a sharp image is obtained. For ordinary lead and lime glasses, monochlorobenzene may be the immersion fluid. The refractive index of this liquid may be adjusted by the addition of small quantities of carbon tetrachloride or monobromonaphthalene.

The Skiagraph.—The resulting image, visual or photographic, is termed a skiagraph because it appears as a cross-section of the object under examination. This is illustrated in Fig. 2. The object in this case is a bulb of a potash tube, and the skiagraph shows clearly the form of the seals between the bulb and the tubes. Fig. 3 shows the cross-section of a construction involving the sealing of a tube within and concentric with a larger tube. In the first case, "A," we have illustrated the acute angle seal. This form of seal between two surfaces is to be avoided because it invariably results in excessive breakage.

Fig. 3, "B," shows the same construction, but with an arched seal. This type of seal can be made with practically no breakage.

The reason for the excessive breakage in the acute angle seal construction, is the stress introduced during the cooling

of the glass from the plastic condition. That portion of the glass in the neighborhood of the apex of the acute angle cannot cool as rapidly as other portions and this uneven cooling results in a stress in the glass at this point. The presence of this stress can be demonstrated by a modification of the set-up shown in Fig. 1. For this purpose it is necessary to convert the set-up into an immersion polariscope, by the use of two Nicol prisms and a sensitive tint plate.

Other modifications of this set-up have been used. For instance, a Balopticon forms a handy means for projecting a skiagraph at any desired magnification. In case only one print is to be made, photographic paper can be substituted for the film or plate. It is not necessary to use monochromatic light for illumination when the skiagraph is taken on a photographic paper. If the index of refraction of the immersion fluid for deep blue light is about the same as that of the article under examination, the resulting photographic image will be quite sharp.

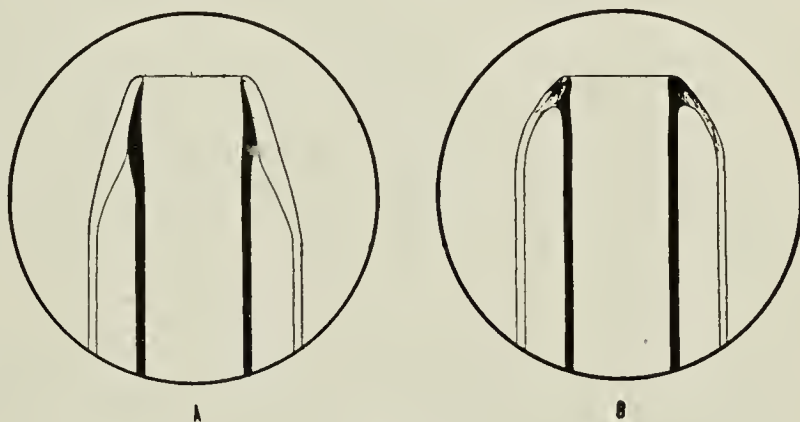


FIG. 3.

A BETTER DESIGN FOR A JUG MOLD CLINCH

By PAUL E. COX

ABSTRACT

A design of a clinch is shown that is suitable for all shouldered ware. This design will give longer life to the molds, yield a better looking product, and do away with cracking at the clinch, and the jiggerman can work more rapidly and easily.

Introduction

Jugs and other shoulder ware made in the usual type of molds have the clinch below the shoulder. Thus the contour of the ware is injured by a ridge which is always at the seam. Since the jiggerman cannot get his hand or a tool inside of the jug, it is apparent that the seam resulting from the usual type of jug mold clinch is a roll of clay a little distance from the shoulder. The cleaning of the jug is rendered difficult on account of this irregular roll of clay. The design described moves this seam to the edge of the shoulder where it is not objectionable in the finished product. Seams on such ware as pickle jars with their open tops can be smoothed with the jiggerman's tommy stick, a stick with a sponge fastened on the end, but with the seam right at the shoulder this work is not needed.

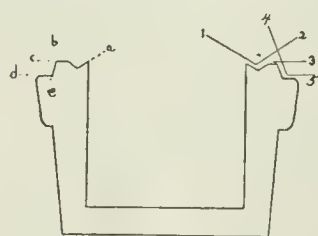


FIG. 1.

Figures 1 and 2 show the usual type of jug mold clinch. In use the edges marked *a* wear down rapidly due to (1) the grinding action of the clay, (2) the dissolving action of the moisture in the clay, (3) the abrasion of the scrapstick used by the jiggerman. The welding together of the two pieces that make up the jug will not be as effective because the jiggerman has the habit of scrapping the work in one direction only. A new mold will shear the surplus clay away and the remainder will be welded. An old one will not do this. A new mold will also cut the clay off entirely or leave but a very thin layer between the knife edges, while an old mold will leave a ridge of clay by which the jug is suspended in the mold during drying. More or less strain is thus set up in the clinch depending on how far drying has progressed, due to the weight of the suspended part of the jug.

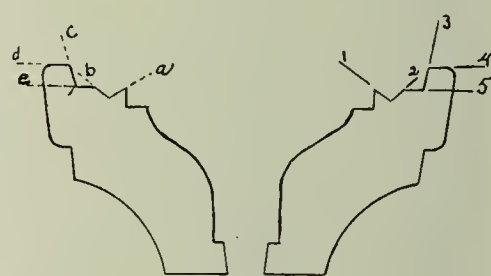


FIG. 2.

In Figs. 1 and 2 the lines marked with the numerals 1, 2, 3, 4 and 5 show the changes of position the right hand of the jiggerman must make in scrapping the clay from the two parts of the ordinary mold. The letters *a*, *b*, *c*, *d* and *e* show the surfaces that the jiggerman must clean from 800 to 1200 times a day or a total of from 8000 to 12,000 surfaces. It is not easy to clean the top part of this kind of jug mold and to do it rapidly.

The numerals 1, 2 and 3 in Fig. 3 show the positions the jiggerman's right hand would take in scrapping the bottom part of this mold, while

the letters *a*, *b* and *c* indicate the surface that must be made relatively clean 800 to 1200 times a day. Two movements per jug have been done away with in this bottom mold, saving a fast jiggerman 2400 movements of his wrist per day, and an ordinary one 1600 movements. In practice it was found that a good jiggerman seldom had to clean surfaces *b* and *c*, thus saving close to 4800 wrist movements per day for this lower part of the jug mold. Figure 4 shows that the jiggerman must move his wrist three times for scrapping the top part of this jug mold. The letters indicate the surfaces that must be made approximately clean. In practice it was not always necessary to clean surface *c*, but to gain time, it was found wise to scrap it. Instead of the jiggerman moving his wrist from 4000 to 6000 times per day he need make only 3600 movements per day.

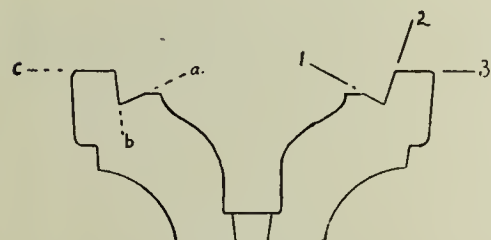


FIG. 4.

It will be seen that this type of mold eliminates a total of 7200 movements per day and while they are all slight movements considerable pressure is applied and energy is used in doing each of them.

Figure 5 shows how the scrapping of the clay is done to insure a good clinch. It is easy to scrap a jar mold and the machine will work the clay above the level of the mold, in spite of the jiggerman's efforts. The jiggerman can then use his scrapstick in the jug mold in such fashion that the clay is not entirely cleared from the mold top, leaving a little wedge around the mold. This is shown in the drawing (Fig. 5). The dotted lines show the shape into which the clay should be scrapped so that when the two parts of the mold are put together the outward pressure will effect a smooth clinch. This upper mold scrapping should be so done that a cone presses down into the neck of a hollow cylinder. The shape of the plaster work makes this work automatic for the jiggerman. It was found that a very slight distortion of the clay took place and that this was in the exact angle of the shoulder.

The block and case work is greatly simplified in this process. This experimental work was done with the assistance of a stoneware jiggerman who kept a record of jugs lost through the cracking of the clinch. In several months' time only five jugs were lost, a number of these resulting from carelessness.

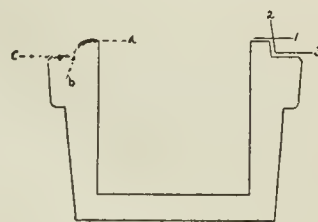


FIG. 3.

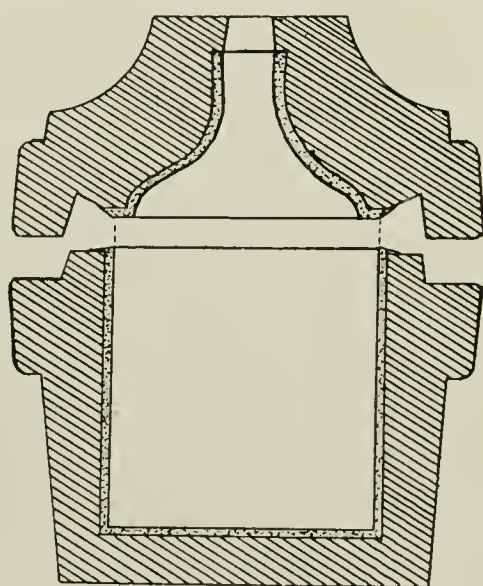


FIG. 5.

THE BEHAVIOR OF FIRE BRICK IN MALLEABLE-IRON FURNACE BUNGS¹

By H. G. SCHURECHT AND H. W. DOUDA

ABSTRACT

Purpose.—An investigation was conducted to study the requirements of fire clay and bodies used for fire brick in malleable-iron furnace bungs. Tests were made on complete bungs holding forty sample brick in malleable-iron furnace bungs with twenty different fire brick. Laboratory tests were also made in conjunction with them.

Results.—The spalling tests bear the closest relation to the service test; those brick losing less than 10% withstand more than fifteen heats.

There is also a relation between the porosities and densities of fire brick, which lie between 15 and 28% and 1.5 and 2.6%, respectively, for the best brick.

There is no close relation between the load test and softening-points of fire brick and their lifetime in malleable furnace bungs, so these tests are no criterions in judging the serviceability of brick, provided the brick are sufficiently refractory to support the arch at furnace temperatures.

Methods for Improving Fire Brick.—The resistance of a brick to spalling may be governed by: (1) the selection of the proper clays, (2) the size of grain and the proportioning of the non-plastic ingredients, (3) the fineness of grain of the bond clay, (4) the manner of molding, and (5) the temperature of firing.

Introduction

In the utilization of fire clays for malleable-iron furnace bung brick, manufacturers have experienced more or less trouble in producing brick of high service due to lack of knowledge of the constitution and properties such a brick should possess. Brick made of clays passing the customary load and softening-point tests often fail when used in malleable-iron furnace bungs. For example, in one case a brick standing a very high load test at furnace temperatures failed under three heats in practice, whereas another brick failing in the load test stood an average service test of 17.5 heats.

In the selection of clays for bung brick, actual service tests are too time-consuming, whereas laboratory tests can be made in much less time. A more thorough study of the relations existing between the laboratory tests of bung brick and their ability to stand up in practice was, therefore, undertaken by the Ceramic Station of the U. S. Bureau of Mines. Although the investigation was limited to brick used in malleable-iron furnaces, the results may be applied to refractories for other furnaces requiring similar service.

Description of Tests

Tests in Practice.—Complete seven-foot arches containing 40 brick were tested as shown in Fig. 1. The number of heats withstood by the

¹ By permission of the Director, U. S. Bureau of Mines. Presented before the Refractories Division, Pittsburgh Meeting, Feb., 1923.

different arches in practice was used as a method of comparing the serviceability of the different brands tested. All the bungs were placed in a definite position over the fire box where they received the same and the severest heat treatment of the furnace. After each heat they were removed from the furnace during re-charging. This chills the brick and tends to cause spalling. The tests were made in a forty-ton malleable-iron furnace operated by the Ohio Malleable Iron Company, Columbus, Ohio. Three or more bungs of each brand of brick were tested.

Laboratory Tests.—The following laboratory tests were made on each brand of brick: (1)

per cent spalling loss; (2) per cent deformation under load; (3) density; (4) per cent apparent porosity; (5) softening temperature; (6) chemical analyses; (7) permeability of gases.

For the spalling test four or more brick of each brand were selected, discarding those showing cracks and flaws. The brick were dried at 110°C for five hours or more, and weighed.

The test furnace was heated to 1350°C and held at this temperature for one hour. The brick were then placed in pairs in $5\frac{1}{4}$ inch x $4\frac{4}{6}$ inch openings left in the doorway of the furnace with the $2\frac{1}{2}$ inch x $4\frac{1}{2}$ inch ends exposed to the fire, and heated one hour before quenching.

Two brick at a time were removed and plunged into running water (about 20°C) to a depth of four inches and held there three minutes, after which they were removed and allowed to dry three minutes in air. As soon as two brick were removed from one of the openings they were replaced by two others, thus preventing cooling of the furnace.

Each brick was heated and quenched ten times. After the tenth quenching they were dried at 110°C for five hours and all particles easily removable by the fingers were broken off. The brick were then weighed and the percentage loss in weight calculated on the original weight as basis.

The resistance of fire brick under load¹ was conducted by applying a load of twenty-five pounds per square inch to the brick and heating them to 1350°C, and holding the furnace at this temperature for one and one-half hours. The per cent deformation was noted and used as a measure of the resistance to load at furnace temperatures.

The softening temperatures were determined by comparison with standard Orton cones.

The apparent densities and porosities were determined by the water and oil immersion methods and calculated as follows:

¹ H. G. Schurecht, "A Machine for Testing the Hot Crushing Strength of Fire Brick." *Jour. Amer. Ceram. Soc.*, 2 [8], 602-7 (1919).

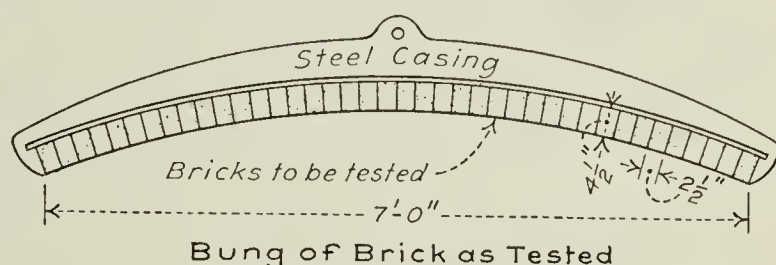


FIG. 1.—Bung of brick as tested.

$$D = \frac{W_d}{V_b}$$

D = density

W_d = dry weight

V_b = bulk volume (true clay volume plus pores)

$$P_a = \frac{W_s - W_d}{V_b} \times 100$$

P_a = per cent apparent porosity

W_s = saturated weight (saturated in water)

The permeability of gases through the brick was measured by forcing air at a low pressure through the two and one-half inch thickness of the brick, and the permeability factor was calculated from the formula below:

$$V = \frac{c l}{t(P - P_o)A}$$

V = permeability factor

c = cc. air passing through

l = length in cms.

t = time in seconds

P = average pressure

P_o = initial pressure

A = area in cm. of cross-section

Results of Tests in Practice and in the Laboratory

Part of the results of this investigation are shown in Tables I and II and Figs. 2, 3, 4, 5, 6 and 7. The results indicate that the load test is no criterion of serviceability in malleable-iron furnace bungs. For ex-

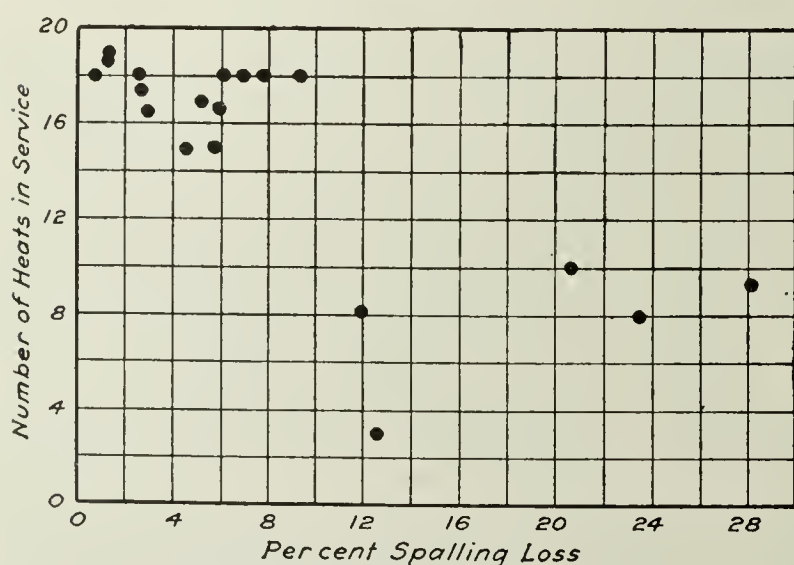


FIG. 2.—Relation between serviceability and spalling losses of fire brick.

ample, bricks B and A behaved poorly in the load test, but stood up well under service, while bricks I and M stood up well in the load test, but behaved poorly in service. Obviously the brick should be strong enough to support the arch at high temperatures, but any extra strength above a safe limit is unnecessary. Brick deforming as much as 6.35% under the load test in some

instances gave excellent service in the malleable-iron furnace bungs.

The softening-point of malleable-furnace bung brick should be sufficiently high to prevent the brick from melting, but it is not necessary for them to stand a high softening-point test, *i. e.*, cone 31 or above. Brick having a softening-point of cone 30 often give as good service as those softening at cones 31–33.

The closest relation of the tests made appears to be between the per cent spalling loss and serviceability. Those brick showing the smallest spalling loss stand up best in practice (see Fig. 2). When the spalling loss was above 10% the number of heats which the corresponding brick withstood in practice were below 15 in each case.

Bricks A, B, to N, were tested when the malleable-iron furnace operated one heat per day. When O, P to S were tested these furnaces operated

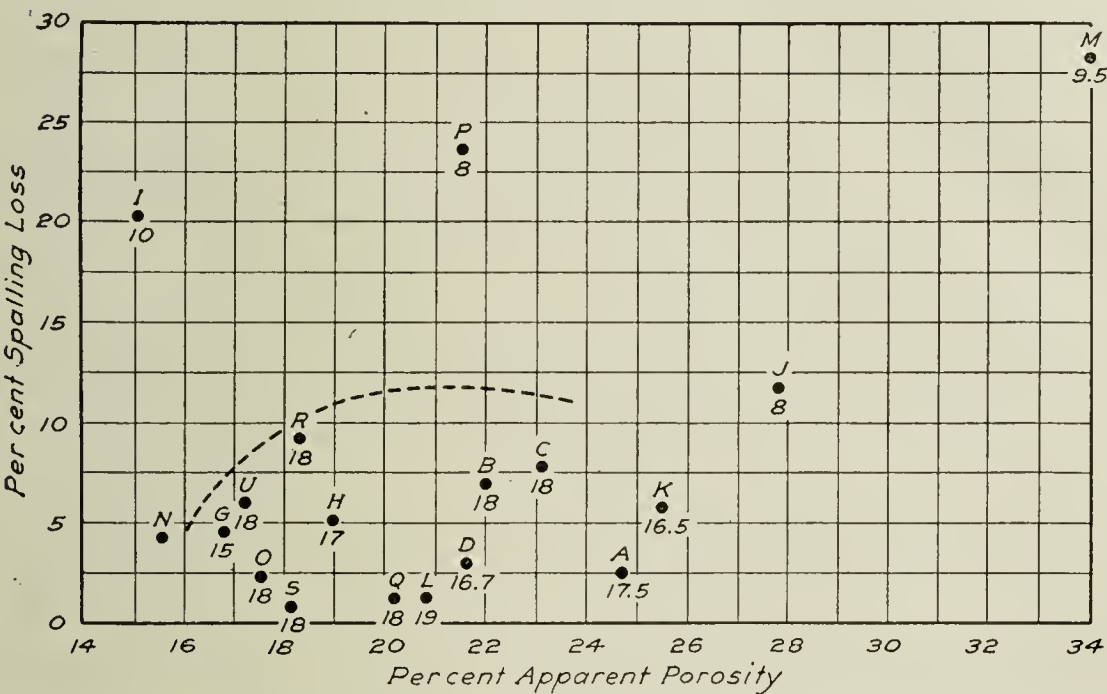


FIG. 3.—Relation between spalling losses and porosities of fire brick and their serviceability.

two heats per day, which treatment was less severe on the bricks than the former method, since the bricks were not as thoroughly cooled in the second

TABLE I

THE CHARACTERISTICS OF MALLEABLE-IRON FURNACE BUNG BRICK

No.	No. heats in malle- able furnace bungs	Per cent spalling loss	Per cent deform under load	Softening point of brick cones	Softening point of bond clay cones	Density	Per cent apparent porosity	Perme- ability of gases
L	19	1.30	0.90	.....	.....	2.282	20.87	0.0197
O	18	2.21	....	.....	.....	1.919	17.46	.....
Q	18	1.16	....	.....	.....	1.935	20.19	0.7405
U	18	6.07	....	.....	.....	2.101	17.18	.....
R	18	9.23	....	.....	.....	1.927	18.29	0.1435
S	18	0.85	....	.....	.....	1.925	18.06	0.2105
B	18	6.94	4.85	30-32	30-31	2.044	22.04	1.3657
C	18	7.92	1.95	32	32	2.025	23.15	.....
A	17.5	2.56	6.35	.....	.....	1.985	24.78	.....
H	17	5.18	0.40	32	30	2.043	19.03	0.3023
D	16.7	2.99	2.05	32	31	2.113	21.67	0.3607
K	16.5	5.80	....	.....	.....	1.958	25.51	.....
G	15	4.36	6.90	32	30	2.188	16.80	.....
E	15	5.31	7.00	31	29	1.978	25.34	0.0630
I	10.0	20.36	1.10	32	30	2.123	15.11	0.464
M	9.5	28.20	0.65	.....	.....	1.910	34.92	1.234
P	8	23.67	....	.....	.....	1.924	21.15	0.7907
J	8	11.94	....	.....	.....	1.888	27.86	0.0350
F	3	12.51	2.80	.....	.....	1.910	20.56	0.1959
Carbo- rundum:	24+	.....	....	.....	.....	.....	.....	.....

method and hence did not spall as much as they did in the first. For example, a brick which stood 1.8 heats when the furnace operated two heats per day, stood 22 heats when it operated two heats per day. Therefore, in Table I the values given for O, P, to S were found by multiplying the number of heats these brick withstood by $\cdot 9/11$.

There appears to be a relation between the porosity of fire brick and their resistance to spalling and their serviceability (see Fig. 3). If a brick is too dense it cracks, due to differences in the expansion of its different portions. A more porous brick is less brittle and yields without cracking to these differences in expansion. When a brick is too porous, however, it also spalls readily. This may be due to the fact that porous brick lack

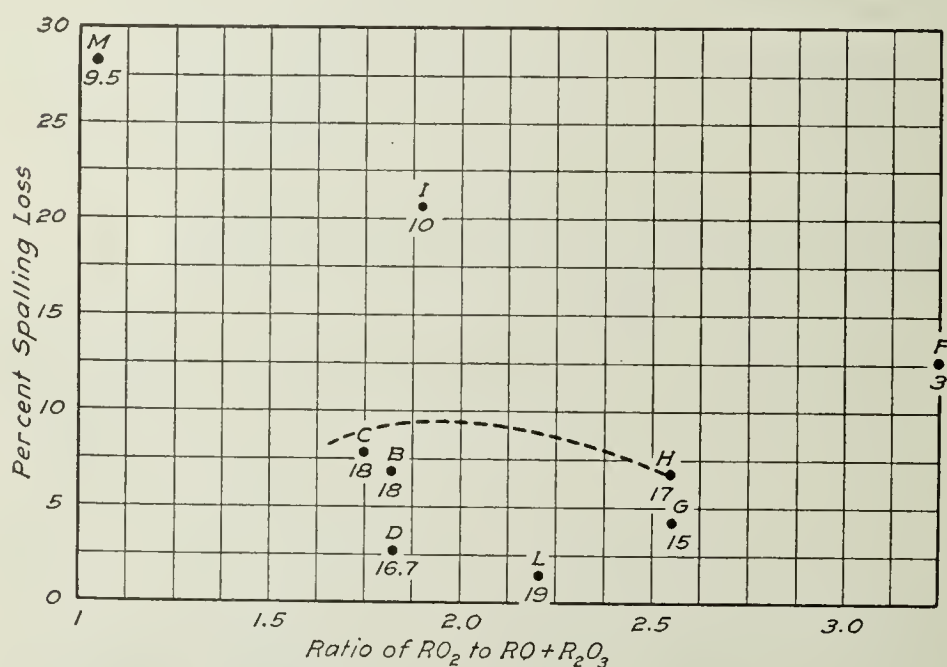


FIG. 4.—Relation between spalling losses and the RO_2 to $RO + R_2O_3$ ratios of fire brick and their serviceability.

On examining the density and porosity data (see Table I and Fig. 3), it appears that brick give best service when their densities and porosities fall between certain limits. These should be neither too high nor too low. The brick giving best service had porosities between 15 and 28%, and densities between 1.9 and 2.3. Those brick whose porosities and densities were outside of this field gave comparatively poor service.

In examining the chemical analyses (see Table II and Fig. 4) it is evident that the RO_2 to $RO + R_2O_3$ ratio of the best brick lies between 1.5–2.6. If the RO_2 (*i. e.*, SiO_2) content is too high, too much free or uncombined silica is present, which increases spalling during heating and cooling, due to the volume changes during the transition of SiO_2 into its various forms at different temperatures. SiO_2 is also more vigorously attacked by the basic slags and gases than Al_2O_3 .

¹ Rieke found that porous ceramic bodies in some cases had almost twice the coefficient of expansion of the same body when vitrified. R. Rieke, "Bestimmung der Wärmeausdehnung einiger Keramischen Massen," *Keram. Rund.*, 14, 143–5 (1914).

mechanical strength and have a higher coefficient of expansion¹ as compared with the more vitreous brick.

Also corrosive gases and slags penetrate a porous brick more readily than a denser one, which would result in producing a more brittle brick and hence one which is more susceptible to spalling.

TABLE II

CHEMICAL ANALYSES OF MALLEABLE-IRON FURNACE BUNG BRICK

No.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Alkalies	RO	RO ₂	No. heats in malleable furnace bungs
							R ₂ O ₃	RO+R ₂ O ₃	
L	54.73	39.25	2.10	0.05	0.05	1.10	2.30	2.21	19
B	52.20	43.42	2.18	0.40	0.40	1.47	1.98	1.83	18
C	51.04	41.04	2.17	0.65	....	4.48	2.05	1.75	18
A	52.93	42.69	1.98	0.33	0.38	1.55	2.04	1.89	17.5
H	58.36	28.76	8.20	....	0.30	3.02	2.93	2.57	17
D	52.60	43.22	2.00	0.40	0.30	1.69	2.01	1.84	16.7
K	54.65	41.36	2.02	0.48	0.29	1.12	2.18	2.03	16.5
G	58.36	28.76	8.20	....	0.30	3.02	2.93	2.57	15.0
E	52.16	43.71	1.98	0.41	0.30	1.68	1.96	1.82	15.0
I	53.75	41.50	2.06	0.39	1.75	....	2.14	1.91	10.0
M	38.40	56.75	2.95	trace	1.10	0.85	1.11	1.04	9.5
J	.....	.....	4.00	....	....	....	....	....	8.0
F	66.22	29.83	1.12	0.27	0.29	1.24	3.69	3.24	3.0
Carbo- rundum	.....	.....	....	....	....	....	....	....	24+

Spalling tests were made on a number of different refractories to determine whether some other refractory was more resistant to spalling than fire clay brick. The results are given below:

TYPE OF REFRACTORY	PER CENT SPALLING LOSS
Fire brick clay	0.63-49.5
Carborundum brick	0
Magnesite brick	Lost over 90% after second quenching
Silica brick	Lost over 50% after second quenching

It is obvious that carborundum brick are much more resistant to spalling than the other refractories tested. Several bungs of carborundum brick were, therefore, tested in malleable iron furnace bungs.

One of the bungs stood up well after 24 heats, after which it was removed because of its high heat conductivity. This service is much higher than that of the fire clay brick tested. The second bung, however, broke the steel casing, due largely to the greater weight of the carborundum brick as compared with fire clay brick. The high heat conductivity of carborundum brick caused the outer surface of the brick to become red, thus allowing considerable loss of heat.

By designing special bung casings much stronger than those used, and by using an insulator between the iron casing and the carborundum brick to prevent heat losses, carborundum brick may prove to be an excellent refractory for malleable-iron furnace bungs because of their great resistance to spalling, and longer service. Carborundum brick, however, are much more expensive than fire clay brick.

The Utilization of Fire Clays for the Manufacture of Malleable-Iron Furnace Bung Brick

It was found in this work in general that a non-spalling brick gave best service in malleable-iron furnace bungs. A dense non-porous brick gave better results than a more porous brick, provided it was not so dense as to be brittle and thus increase the spalling tendency.

The above properties are governed largely by: (1) The selection of the proper clays, (2) the size of grain and the proportioning of the non-plastic

to the plastic ingredients, (3) the fineness of grain of the bond clay, (4) the manner of molding, and (5) the temperature of firing.

The density and porosity of fire brick can be controlled by the proper selection of clays, and by proper firing. Some clays are porous when fired at high temperatures, while others are

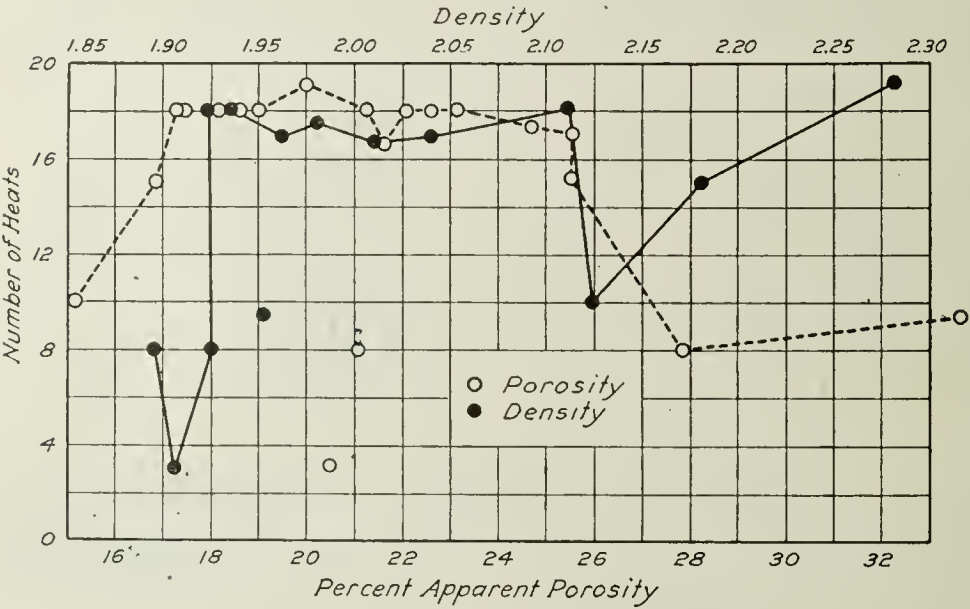


FIG. 5.—The relation between serviceability and the porosities and densities of fire brick.

vitreous. By proper blending of these two types of fire clays, a mixture may be obtained, giving any desired porosity. The method of molding also affects the density and porosity of fire brick, as is shown below.¹ The following brick were made with 30 bond clay and 70 grog.

Method of molding	Per cent shrinkage	Per cent absorption	Compression strength, kg./cm. ²
Soft mud	5.0	10.7	87
Soft mud and repress	4.9	9.6	88
Tamped brick	4.8	8.9	103
Dry press	5.1	12.7	50

These results show that a mixture with less water than soft mud consistency and with more water than dry press consistency produces the densest brick providing sufficient pressure is used in molding.

The size of grain and proportioning of flint clay² has a marked effect on the spalling tendency. Those brick containing a high percentage of coarse grog are more resistant to spalling than those containing fine-grained grog. A series of tests in which 1 x 1 x 8 inch bars were heated to

¹ "Verein deutscher Fabriken feuerfester Producte," 1914.
² F. A. Kirkpatrick, *Trans. Amer. Ceram. Soc.*, 19, 287 (1917).

600°C and quenched in water until they broke were conducted by Kirkpatrick on bars containing 50% bond clay and 50% grog. The average results obtained with the different series are given below and show that using coarse grog instead of fine increases the resistance of fire brick to spalling.

Size of grog in mixture	Number of quenchings before specimens broke due to spalling
4-20 mesh	11.1
8-20 mesh	9.3
12-80 mesh	7.5
20 dust	4.7

Increasing the percentage¹ of flint clay and reducing the percentage of bond clay increases the resistance of fire brick to spalling within certain limits.

The size of grain of the bond clay also affects the spalling tendency of fire brick. For example, it is shown in Fig. 7 that fire clay screened through a 20-mesh sieve is much more resistant to spalling than the same clay ground fine enough to pass a 150-mesh sieve.

Different firing temperatures have a marked effect on the properties of fire brick. For example, it was found² that when clays of the fire clay type are fired to cone 8, they are often stronger than when fired to cone 6 or 10, even when the porosity and shrinkage data showed the bodies to be over or underfired at this temperature. Investigations on the effects of different firing temperatures³ on the spalling tendency of fire clays and fire brick show that the firing temperature has an important effect on the spalling of the brick. Fire clay bars, 1 x 1 x 8 inches, previously fired to cones 6, 8 and 10, were heated to 600°C and plunged into water five times,

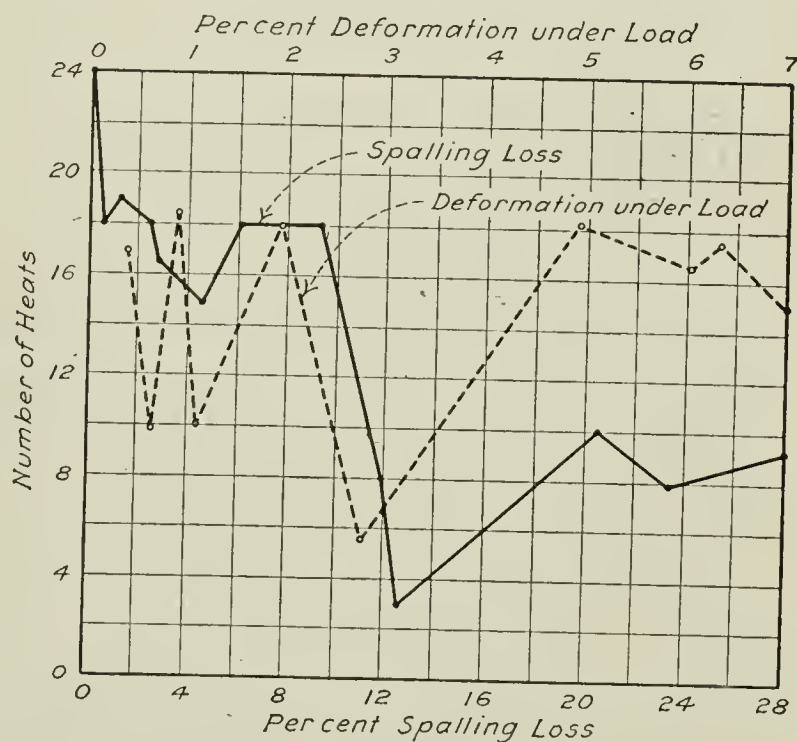


FIG. 6.

¹ R. M. Howe, "The Use of Plastic Clay Grog in Preventing Spalling," *Jour. Amer. Ceram. Soc.*, 4 [2], 119 (1921).

² H. G. Schurecht, "Notes on the Effects of Firing Temperatures on the Strength of Fire Clay and Stoneware Bodies," *Jour. Amer. Ceram. Soc.*, 4 [5], 366-74 (1921).

³ "The Properties of Some Stoneware Clays," U. S. Bureau of Mines, *Tech. Paper* 233, 26 pp. (1920); R. M. Howe and R. F. Ferguson, "A Study of Spalling," *Jour. Amer. Ceram. Soc.*, 4 [1], 40 (1921).

after which their strength was measured. The strengths of those bars which had been fired to cone 8 were higher after the quenching treatments than those fired to cone 10 and in some cases they were stronger than those fired to cone 6 (see Fig. 7).

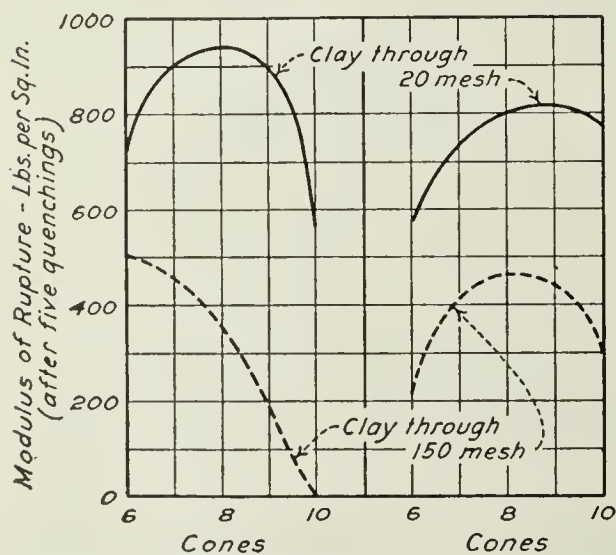


FIG. 7.—The effects of firing temperatures and fineness of grain of fire clays on their resistance to spalling.

It appears, therefore, that by firing brick to cone 8, a product is often obtained which is more resistant to spalling than when fired to cone 10. This may be due to the presence of sillimanite and free silica in the fire brick, which are formed at high temperatures.

Summary

The work on malleable-iron furnace bung brick, which has been done up to the present time, has not been extensive enough to draw definite conclusions. The writer, however, offers the following summary, which applies only in so far as the work has progressed:

Fire brick for malleable-iron furnace bungs should be strong enough to support the arch at high temperatures, but it is not necessary that the brick should stand as high a load test and fusion test as are required for No. 1 fire brick. Fire brick which may deform as much as 6.35% in the load test may be very serviceable as bung brick in malleable-iron furnaces.

Although brick which pass very high load and softening point tests often give good service in practice, many which pass these tests fail.

The spalling test bears the closest relation to the service test. When the spalling loss was above 10%, the number of heats which the corresponding brick withstood in practice was below 15. In general, brick showing a spalling loss below 10% withstood 15 or more heats in practice.

The brick giving best service had porosities between 15 and 28% and densities between 1.9 and 2.3.

The RO_2 to $RO + R_2O_3$ ratios of the best brick were between 1.5 and 2.6.

Carborundum brick withstood more heats than any fire clay brick tested, but are objectionable due to their high heat conductivity and greater weight. These objections, however, can be overcome by using heat insulation and stronger casings.

In the manufacture of malleable-iron furnace bung brick, their properties may be governed by (1) the selection of the proper clays, (2) the size of grain and the proportioning of the non-plastic and plastic ingredients, (3) the fineness of grain of the bond clay, (4) the manner of molding, and (5) the temperature of firing.

NOTE:—In conclusion, the author wishes to acknowledge his indebtedness to J. M. Kittle of the Ohio Malleable Iron Company, and J. S. McDowell of the Harbison-Walker Company, for their coöperation in this work.

CERAMIC EXPERIMENT STATION
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Discussion

C. E. BALES:—This paper is a valuable contribution not only to the user of refractories, but also to the manufacturer. We fully agree that the load test is of no value in determining the quality of bung brick as we know of brick deforming as much as 8.7% in this test, which gave excellent service.

In our work the brick showing the least spalling loss has always given the best results in actual service. We have found that brick with a high fusion point (cone 33), iron oxide content less than 2.5% and alumina between 40 and 45% have stood up best in service. Brick high in silica (68%) gave only 4 heats in service, the failure being due to spalling.

Our experience agrees with Mr. Schurecht's opinion that the porosity of fire brick is an important property and that bung brick will fail if they are too porous as well as if they are too dense.

We were surprised to learn that bung brick with 8.20% Fe_2O_3 would give 17 heats in a malleable-iron furnace.

It is doubtful if carborundum brick will ever be used extensively in malleable-iron furnaces on account of their high cost, high heat conductivity, their weight, and the fact that they begin to dissociate at about 2725°F under oxidizing conditions and at about 3100°F under reducing conditions.

A PROPOSED METHOD FOR STUDYING THE ATTACK OF MOLTEN SLAGS AND GLASSES UPON REFRACTORY MATERIALS¹

BY CHARLES I. ROSE

ABSTRACT

A new method of studying the attack of molten glasses and slags upon refractory materials, whereby the refractory tested is rotated in a glass or slag melt under arbitrary conditions, is described. The solution and penetration of the refractory are measured separately by means of a micrometer and simple microscope, and some of the advantages of this procedure are enumerated.

Introduction

The action of molten slags or glasses upon refractory materials is a consideration of prime importance.

There are two general and distinct phases into which the attack of these glasses or slags may be divided. These are (1) the solution or removal of a portion of the refractory body causing a shrinkage of dimensions of the original piece, and (2) the penetration of the remaining material. The combined effects of simple solution, chemical reactions between the body and molten liquid, and the abrasive action of the slag or glass upon the refractory are gathered together under the first division. Penetration on the other hand is used to refer to such action of molten liquids upon the bodies which does not result in any reduction of the dimensions of the materials. The filling of the pores of a refractory below its surface illustrates this.

Any method whereby the action of molten substances upon refractories is to be studied should (1) permit easy differentiation to be made between the two phases of the attack as listed above, (2) be simple, and adaptable to various conditions, (3) give quantitative results, (4) preserve the characteristics of the material to be tested instead of destroying them previous to or during a test.

Some previously published methods of studying this attack are listed below.

E. A. Coad-Pryor² investigated the solution of glass pot mixtures in various glasses. His method consisted of making small rods of the material to be used, and then immersing them in a small pot containing the molten glass. After a given period of immersion the rod was withdrawn, and the effect of solution noted. The results were purely relative.

G. H. Brown³ used a somewhat similar procedure to the above. He

¹ The following paper describes a method used by the author in preparation of a thesis which partially fulfilled the requirements for the degree of Master of Science in Ceramics at the University of Illinois.

² E. A. Coad-Pryor, "Notes on Pot Attack," *Jour. Soc. Glass Tech.*, **2**, 285 (1918).

³ G. H. Brown, "A Method of Testing the Corrosive Action of Slags on Fire Brick," *Trans. Amer. Ceram. Soc.*, **18**, 277 (1916).

immersed a brick of the refractory material in a box or sagger of molten glass. After a definite period of immersion the box was cooled, and the brick broken from the solidified mass, and the results noted. The results are also relative.

The American Society for Testing Materials¹ has adopted a tentative standard for studying the slagging action of refractories. The method consists in melting synthetic slag within a fire-clay ring placed on the surface of the refractory. The slag is maintained in a molten condition for a certain period at a definite temperature. After cooling, the brick is sawed through the middle of the ring, and the area of penetration of the slag is measured by means of a planimeter. The results are very indefinite.

Recently R. M. Howe² in an article discussing the phases of slag attack gives some data based upon results obtained by allowing a molten slag to seep into the refractories used, and then noting the penetration.

As a continuation of the above he has, with the coöperation of Howe, Phelps and Ferguson³ presented a later article dealing with the dissolving action of the slag on the refractory. In this procedure the refractories are ground to pass a certain mesh, mixed with varying proportions of the slag used, molded in the shape of cones, and the melting points of these cones determined. In this test the texture and some of the physical characteristics of the refractory are destroyed previous to the test.

Accelerated Slag Test

The purpose of our investigation was to devise an accelerated test without increasing the temperature above that used in ordinary practice. The advantage of this procedure is that any compounds present in the refractory which are stable at practical operating temperatures are preserved, whereas a higher temperature might destroy them, and so give the refractory the appearance of having properties which it did not actually possess under ordinary operating conditions. Briefly, the proposed method consisted in rotating cylinders of the refractory material in a pot of glass under conditions which should be as nearly reproducible as possible for the various refractories in relation to each selected glass. After rotating the cylinder in the molten glass for a desired period, the solution and the penetration were measured by means devised for this process, and the results were expressed in a definite manner.

¹ A. S. T. M. Tent. Stand., 293 (1922).

² R. M. Howe, "A Study of the Slag Test," *Jour. Amer. Ceram. Soc.*, **6** [2], 466 (1923).

³ R. M. Howe, S. M. Phelps and R. F. Ferguson, "Action of Slag upon Silica, Magnesite, Chrome, Diaspore and Fire-clay Refractories," *Jour. Amer. Ceram. Soc.*, **6** [4], 589 (1923).

Abrasion and Chemical Reaction.—The two most influential factors in producing solution of a given refractory body are the abrasive effect caused by the rotation of the cylinder in the molten glass, and the chemical reactions taking place between the refractory material and the glass. The abrasive action of the glass or slag will vary directly with the rate of rotation, while the chemical effects will depend upon the differences in chemical characteristics between the two materials at the temperature of operation of the test. The former can be controlled at any time, but the latter can be controlled only by changing the temperature or altering the glass composition. Simple solution will also have an effect, but this will probably be very small in connection with the two mentioned above. In any case the solution measured is the total amount regardless of the manner in which it was produced.

Viscosity of Glass.—The factors influencing the penetration of the body are the viscosity of the glass or slag, the porosity of the body tested, and the size of pores in that body. The viscosity of the molten mass can be altered at will within limits by changing the temperature, but the porosity and the size of pores of the refractory body depend upon the preparation of the body, and are uncontrollable insofar as the test is concerned.

The factors in the test which can be altered at will are the rate of rotation of the cylinder, the length of time employed in the test, the kind of slag or glass used, and its viscosity which is dependent upon the temperature selected.

Apparatus Used.—A platinum resistance furnace was used for the tests. The heating element was wound around a grooved clay pot which was well insulated. A smaller clay pot containing the glass was placed in the first pot. These pots were made to fit snugly, but to prevent any rotation of the inner pot it was lightly cemented to the outer one with some plastic clay. A thermocouple inserted between the walls of the two pots allowed the temperature to be read. The usual ammeter, voltmeter and rheostats were employed. A fuse was placed in the line as an extra precaution so that if any short circuits took place by accident in the heating element, the fuse would blow before the platinum wire would be melted. Close control of the furnace temperature was possible as compared to practice. Variation in the temperature was usually 10° , and never varied over 15° .

The furnace was placed upon a platform which could be raised or lowered by means of a screw and threaded ring. Above the furnace was a support for the rotating device. The top of the support held a platform made of asbestos board through a hole in which the rotating shaft passed. The driven pulley was fastened to the upper end of this shaft, and to the lower end was secured a collar having a number of set screws in which the spindle

holding the cylinder was fastened. A small constant speed motor operating through a series of reducing gears rotated the spindle.

Procedure.—The glass cullet used was melted in the furnace while it was in the lowered position. All glasses had previously been prepared in a separate furnace. The refractory cylinder, the average diameter of which had also been measured at a certain point, was inserted in the spindle, and that in turn in the collar, and then the furnace was raised until the cylinder was well immersed in the molten glass. Since the introduction of the comparatively cold cylinder into the glass chilled it, some minutes' wait was necessary to restore the temperature of the glass. After the temperature had been regained the piece was then started rotating at the desired speed.

When the test had continued as long as desired the furnace was lowered with the cylinder rotating until entirely clear of the surface of the glass. A thread of glass formed between the end of the piece and the surface of the glass which could be broken easily by a sharp rap with some tool. The cylinder was then removed from its holding device with a uniform coating of glass, and placed while hot in a heated drier to cool slowly. After cooling the necessary measurements were made.

Measurements.—Before the test the average diameter of the burned cylinder in a given plane on its length was determined by taking the mean of a number of diameters in that plane. The location of the plane was noted definitely.

After the test the piece was cut through by means of a thin cut off wheel at the point established. This gave a plane face on the end of the cylinder. The center of this circle was established by noting the point of intersection of lines joining the points of tangency of the two parallel jaws of a caliper across the face of the cylinder. This point was further checked by measuring from it to other points on the circumference of the piece. After having found the center then any straight line through it was necessarily a diameter.

The piece was then set with this flat surface directly under the tube of a simple microscope and it was brightly illuminated. The established center was placed directly under the intersection of the two fixed cross hairs in the ocular of the microscope, and the cylinder was held successively in such positions that the travel of the microscope tube across the face through the established center was the trace of the previously measured diameters.

The distance traveled was measured by subtracting the two lengths of supporting rod extending from a fixed part of the microscope's structure which were necessary to bring the cross hair directly over the line of demarcation between the glass and body at the ends of a selected diameter.

The penetration could be measured by means of a calibrated traveling

cross hair in the ocular. The depth could be easily observed under the microscope.

Measurements were made with a wide-jawed micrometer graduated to ten-thousandths of an inch. In all cases the division line between the glass and body stood out distinctly when illuminated, and very accurate settings of the cross hair were possible.

It was also found that the method of cutting off the end of the cylinder by means of a thin grinding wheel was very satisfactory. The glass adhering to the cylinder, though cracked due to the cooling of it under these conditions, nevertheless adhered firmly to the body. The cutting process did not chip it off as might be expected which would be the case if an attempt were made to grind the cylinder down against a large wheel.

Since the rate of removal of the refractory from the glass, and also the rate of insertion into it could be controlled as desired any tendency to spall on the part of the refractory was counteracted. However, this could be made the basis of a slightly modified spalling test.

Results

The solution of the body was expressed as the rate per day in inches at which it took place. The unit employed is purely arbitrary. It is to be noted in connection with the solution as affected by the rate of rotation that a definite rate of rotation refers to a definite linear velocity of a point on the circumference of any given cylinder. Since the diameters of the cylinders varied it was necessary to calculate the revolutions per minute necessary for each piece to give a selected linear velocity. This latter figure could be selected as desired.

The penetration of the molten glass or slag was measured and noted in inches. As no methods of measuring the sizes of pores in the body, or of ascertaining their number and distribution easily were available this was the only manner in which to express the result. However, results so far obtained show that if the porosity of the pieces tested is known, then the relative sizes and numbers of pores could be determined in comparison with another body due to differences of penetration under the same conditions. In other words if a body of high porosity shows less penetration than one of lower porosity when tested under identical conditions, then the first material had smaller pores, and penetration by the molten glass was more difficult than in the second case.

Investigations of various types of refractory materials are being carried out now in the Laboratory of the Department of Ceramic Engineering at the University of Illinois by means of this method, and results already obtained seem to indicate that the procedure outlined above has certain advantages over others which have been previously proposed.

Summary.—The procedure described above for studying the attack of

molten glasses and slags upon refractory bodies promises to give a method which will (1) permit the solution and penetration of the refractory by the glass or slag to be easily distinguished and measured, (2) give quantitative results, and be very accurate, (3) employ simple apparatus which is readily constructed, and such as will permit the general plan of the method to be executed, (4) not destroy the peculiar characteristics and properties of the refractory previous to or during the test, (5) require no special precautions to perform, (6) give the relative size of pores in the body when the porosity is known, and (7) permit a wide variation in conditions any of which may be fixed as desired for any particular investigation.

NOTE:—The author wishes to express his indebtedness to C. W. Parmelee who suggested the general method of attack, and gave much valuable advice.

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THE ORIGIN, DISTRIBUTION AND COMPOSITION OF LATERITE

BY C. O. SWANSON

ABSTRACT

The term laterite means a red rock or red earth deposit. Laterites are formed by the decomposition of different kind of rocks, under conditions yielding aluminum and iron hydroxides. The different theories of origin are discussed, as well as the chemical process of laterization, and the geographic distribution of this peculiar type of clay.

Introduction

The term laterite comes from the Latin word *later* meaning brick or tile, and was first suggested by Buchanan,¹ because the prevailing color of laterite is red and they are quite commonly hard.

The term laterite includes a variety of materials. Clarke² defines laterite as essentially a mixture of ferric hydroxide, aluminum hydroxide and free silica in varying proportions. Dixey³ defines laterite as a rock of variable composition, consisting of the hydrated oxides of iron, aluminum, titanium and rarely manganese. La Croix's definition of laterite as reported by Fermor⁴ is: "The products of decomposition of all siliceous and aluminous rock, characterized from a chemical point of view by the predominance of hydroxide of aluminum and iron, generally with titanium oxide."

According to La Croix⁵ the term laterite should be restricted to the products of decomposition of diabase, gabbros and especially to materials of light color such as result from the transformation of granites and syenites. Red color is not to be considered a specific of laterite.

Clay is a hydrated aluminum silicate while laterite is a mixture of oxides more or less hydrated.⁶ These mixtures of hydrated oxides are extremely variable in composition, some are almost free from iron, others are almost free from alumina. Some laterites are used as an iron ore and others as aluminum ore. Warth and Warth⁷ say that laterite is bauxite in various degrees of purity, from the richest wocheinite down to such specimens in which the free alumina has entirely disappeared.

Laterite is not a simple substance but a material which may differ widely in chemical composition and physical characteristics, and yet the material

¹ Buchanan, "Manual of the Geology of India," 348 (1879); 349 (1881).

² F. W. Clarke, "Data of Geochemistry," U. S. Geol. Surv., *Bull.* 616, 493-501 (1916).

³ F. Dixey, "Notes on Laterization in Sierra Leone," *Geol. Mag.*, 57, 211-220 (1920).

⁴ L. L. Fermor, "The Work of Professor La Croix on the Laterites of French Guiana," *Geol. Mag.*, 2, 28-37, 77-82, 123-129 (1915).

⁵ A. La Croix, "Les Produits des Roches Silicate set Alumineuses, et en Particulier les Laterites de Madagascar," *Compt. rend.*, 159, 617-622 (1914).

⁶ L. L. Fermor, "What is Laterite?" *Geol. Mag.*, 8, 454-462; 507-516 (1911).

⁷ H. Warth and F. J. Warth, "The Composition of Indian Laterite," *Geol. Mag.*, 10, 154-159 (1903).

must have certain properties and characteristics in order to be classed as a laterite.

Distribution of Laterites

Many writers believe that laterites are a product of tropical conditions. As tropical conditions have not always been confined to the tropics of the present day laterites may be found in the higher latitudes. Laterites are widely distributed geographically but occur in the largest amounts in the tropics.

The laterites of India are described by Fermor,¹ Holland,² Maclaren,³ Warth and Warth,⁴ Fox,⁵ Lang,⁶ Dunstan,⁷ and others. The work of Baur⁸ on the laterites of Madagascar and Seychelle Islands, and of La Croix⁹ on the laterites of French Guiana and Madagascar are from the standpoint of completeness of the greatest importance. Besides these, laterites from the following localities have been studied: Sierra Leone,¹⁰ Mozambique,¹¹ British Guiana,¹² West Africa,¹³ West Australia,¹⁴ New Caledonia,¹⁵ Sudan and Congo,¹⁶ Rhodesia,¹⁷ East Africa,¹⁸ Malay Penin-

¹ L. L. Fermor, "Manganese in Laterite," *Memoirs of the Geol. Surv. of India*.

² T. H. Holland, "On the Constitution, Origin and Dehydration of Laterite," *Geol. Mag.*, **10**, 59-69 (1903).

³ Malcolm Maclaren, "On the Origin of Certain Laterites," *Geol. Mag.*, **3**, 537-547, (1906).

⁴ H. Warth and F. J. Warth, *loc. cit.*

⁵ Cyril Fox, "The Bauxite Resources of India," *Mining Mag.*, **26**, 82-96 (1922).

⁶ Richard Lang, "Geologisch—Mineralogische Beobachtungen in Indien," *Centralblatt für Mineralogie*, 641-653 (1914); 148-160 (1915).

⁷ W. R. Dunstan, "Report on Laterite from the Central Provinces, India," *Record Geol. Surv., India*, **32**, 213-220 (1903-1904).

⁸ Max Baur, "Beirtag zur Kenntniss des Laterits, insbesondere dessen von Madagascar Neues Jahrbuch für Mineralogie, Geologie und Paläontologie," *Festband*, 33-90 (1807-1907).

⁹ A. La Croix, "Les Laterites de la Guinée et les Produits d'Alteration qui leur sont Associates," *Nouvelles Archives du Musee*, **5** [5], 255-356 (1914).

¹⁰ F. Dixey, *loc. cit.*

¹¹ T. H. Holland, *loc. cit.*

¹² J. B. Harrison, "Laterites in British Guiana," *Geol. Mag.*, **7**, 439-452; 488-495; 553-562 (1910).

¹³ J. Morrow Campbell, "The Origin of Laterite," *Trans. Inst. Mining and Metallurgy*, **19**, 432-435 (1909-1910).

¹⁴ W. G. Woolnough, "The Physiographic Significance of Laterites in Western Australia," *Geol. Mag.*, **5**, 385-393 (1918).

¹⁵ W. M. Davis, "Metalliferous Laterites in New Caledonia," *Proc. Nat. Acad. Sci.*, **4**, 275-280 (1918).

¹⁶ H. Arsandaux, "Laterite Formation," *Compt. rend.*, **149**, 682-685, 1083-1084 (1909); *C. A.*, **4**, 888 (1910).

¹⁷ F. P. Mennel, "Notes on Rhodesian Laterite," *Geol. Mag.*, **6**, 350-352 (1909).

¹⁸ L. L. Fermor, *loc. cit.*

sula,¹ and laterite from Ceylon, China and Caucasia.² The laterites of South America have been comparatively little studied, although they are probably the most important in the world.²

If it is accepted that bauxites are laterites especially rich in alumina, then, it follows that there are deposits of laterites in the temperate climates. The bauxite deposits of Arkansas,³ Georgia,⁴ and Alabama, show similarities to many laterites. Kilroe⁵ describes a deposit in Vogelsberg, Germany, which is very much like laterite and also like bauxite. The similarities in chemical composition of laterites and bauxites, can be seen by studying the figures given in Tables I–VII.

A hard crust overlying the laterite seems to be common. It is not seen in gibbsitic laterite. The hardness is invariably increased on exposure to the air.⁶ Harrison⁷ ascribes the cause of hardening in part to changes in the degree of hydration of the hydrated oxides of iron and aluminum, and the gradual conversion of soluble colloidal forms to insoluble ones. Hardening of the lateritized surface is a usual but not a necessary accompaniment of laterite formation.

Rocks Which Furnish Materials for Laterite Formation

Laterite may be formed from several kinds of rock. Baur² gives analyses of laterites derived from granite, diabase amphibolites and sandstone, and Lenz⁸ gives analyses of laterites formed from clays and sandstone. Laterite occurs over basalt and gneiss of different varieties.

According to Harrison⁷ rocks in which plagioclase feldspar are abundant with their usual concomitants of ferromagnesian minerals, form laterites by decomposition *in situ*. Rocks in which alkali feldspars predominate as a rule decompose into kaolins.

It appears that the process of laterization has more to do with the character of the laterite formed, than the nature of the parent rock. It is evident that the rock must contain the necessary content of aluminum and iron. The relation between the parent rock in one region may not be the same as in another region which is widely different in climate and physiography.

¹ L. H. Fermor, *loc. cit.*

² Max Baur, *loc. cit.*

³ W. J. Mead, "Bauxite Deposits in Arkansas," *Econ. Geol.*, 10, 28–54 (1915).

⁴ T. L. Watson, Georgia Geol. Surv., *Bull.* 11.

⁵ J. R. Kilroe, "On the Occurrence and Origin of Laterite and Bauxite in the Vogelsberg," *Geol. Mag.*, 5, 534–542 (1908).

⁶ J. Morrow Campbell, *loc. cit.*

⁷ J. B. Harrison, *loc. cit.*

⁸ Rudolph Lenz, "Chemische Untersuchung über Laterit," Inaug.-Diss. Freiburg i Br., 45 (1908); Referat Max Bauer, "Neues Jahrbuch für Mineralogic," *Geologie und Paläontologie*, 2, 347 (1909).

Laterization as Affected by Climate

Laterites have arisen from the decomposition of aluminous minerals by changes that seem peculiarly characteristic in the tropics,¹ due to the action of the tropical forest on the soil.² Laterite deposits are restricted geographically because they require for their formation tropical heat, heavy rainfall and luxuriant vegetation.³ They also require wet and dry seasons,⁴ and elevated plains on gently sloping land surfaces not subject to appreciable erosion. Harrison⁵ claims the evidence does not prove that the production of laterite is confined to hot, moist climates. He admits, however, that the preservation of the laterite deposits is largely confined to tropical countries, as under temperate conditions of denudation, detrition and lack of hardening the accumulation of laterites *in situ* to a great depth would be impossible.

Holmes⁶ observes with reference to the laterites of Mozambique that none occurred at the surface where the forest and undergrowth were thick. The deposit was almost always associated with areas where the superficial layer was clean, free from organic matter and so-called humous acids. This observation is not so contradictory as would first appear. The laterites may have been formed under forest conditions, but since their formation the vegetation has perished.²

Campbell⁷ says that luxuriant vegetation and tropical temperatures are advantageous but not indispensable. Lang⁸ observes that the laterites of India are found only under the brown and humous soil, and all evidence points to the fact that laterite is a fossil deposit, belonging to a past period of dry climate. Mead⁹ thinks that one reason why laterization has largely been confined to the tropics is that through the action of frost, the open cellular structure is destroyed, allowing the clays to slump and become impervious, thus checking further alteration of clays in regions subject to frost. It seems that an open cellular structure, or at least porosity, is one of the essential conditions for laterization to take place on an extensive scale.

Holland's¹⁰ theory of the origin of laterite differs from all others. Ac-

¹ Max Baur, *loc. cit.*

² Malcolm Maclaren, *loc. cit.*

³ H. Stremme, "Die Entstehung des Laterits," *Zeits. der Gesell. für Erd kunde zu Berlin*, 2 (1917); Biederman's *Zentralblatt für Agr. Chemie*, 48, 51-52.

⁴ Cyril Fox, *loc. cit.*

⁵ J. B. Harrison, *loc. cit.*

⁶ Arthur Holmes, "The Laterite Deposits of Mozambique," *Geol. Mag.*, 1, 529-537 (1914).

⁷ J. Morrow Campbell, *loc. cit.*

⁸ Richard Lang, *loc. cit.*

⁹ W. J. Mead, *loc. cit.*

¹⁰ T. H. Holland, *loc. cit.*

According to this investigator, laterite formation is due to the agency of lowly organisms, possibly akin to nitrifying bacteria. Holland claims that this theory would account for the following facts: (a) Laterites are most extensively developed under tropical conditions; (b) Although laterites may be 100 or more feet in thickness there is a sharp change from the soft decomposed product to the absolutely fresh rock below; (c) That though laterites can form in temperate climates, the seasons of cold are inimical to these microorganisms; (d) Laterite is a superficial product.

From most observations, it appears that a hot, moist climate is a favoring condition if not an absolute necessity. Bauxites are found in comparatively few places in the higher latitudes.

The General Process of Laterite Formation

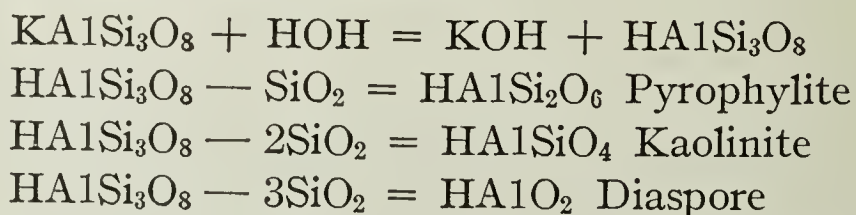
When a rock is converted into laterite,¹ the silicates are decomposed and the silica is removed in solution. While the oxides of iron and aluminum are relatively soluble under clay forming conditions, they are relatively insoluble under laterite forming conditions. The oxides of calcium, magnesium, sodium and potassium are soluble under both sets of conditions. From this it is not concluded that aluminum is insoluble. Under conditions of laterization it is capable of entering into solution and being redeposited as aluminum hydrate when the conditions are favorable.

In general the chemical process of laterization means the elimination of the alkalis, alkaline earths, and silica from the original rock, and the persistence of the hydrated oxides of aluminum and iron with a small amount of titanium oxide. The aluminum is left chiefly in the form of hydrargillite and the iron as hydrous oxide.

Laterization Compared with Kaolinization

The chemical equation for the production of kaolinite from feldspars, an essential process in the formation of clay, may be written: $K_2O \cdot Al_2O_3 \cdot 6SiO_2 + CO_2 + 2H_2O = Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O + K_2CO_3 + 4SiO_2$.

The equations given by Cameron and Bell² showing hydrolysis followed by splitting off of silica are as follows:

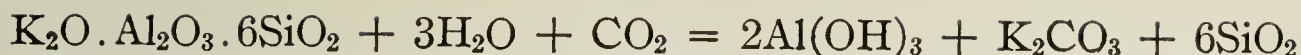


The equation for the production of laterite as adapted from Maclaren³ may be written:

¹ L. L. Fermor, *loc. cit.*

² Frank K. Cameron and James B. Bell, "Mineral Constituents of the Soil Solution," U. S. Dept. of Agriculture, Bur. Soils, *Bull.* 30.

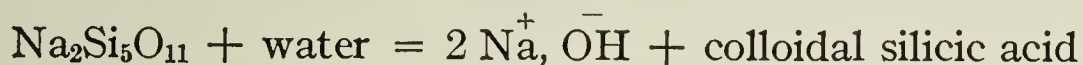
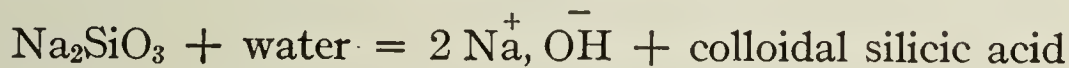
³ Malcolm Maclaren, *loc. cit.*



These equations show that chemically the processes of kaolinization and laterization are similar, the latter being a further step in the elimination of silica from the weathered product.

In laterization all the minerals produced are in a state of hydration either colloidal or crystalline and most often the two together.

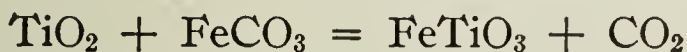
The work of Kahlenberg and Lincoln¹ has shown that silicates in contact with water produce colloidal silicic acid.



This chemical process has a most important bearing on laterite formation where one of the essential processes is the removal of silica which would be carried away in colloidal form by water.

Titanium in Laterite

Titanium is the element which suffers the least loss in the transformations which produce laterite. It is usually present in the form of rutile, TiO_2 , or as ilmenite, FeTiO_3 , or titaniferous magnetite. The first two may be produced from sphene according to Van Hise.²



The tables which follow show that titanium is present in many laterites in considerable amounts.³ Titanium is found not only in bauxites and laterites, but it is also present in most soils.⁴

Zone of Leaching and Zone of Concretion

La Croix³ introduces two descriptive terms which help to clarify our ideas regarding laterite formation. These are "Zone of Leaching" and "Zone of Concretion."

Zone of Leaching.—"This zone is characterized by the elimination of the greater part of the constituents, whose removal characterizes the phenomena of laterization. Three cases can be distinguished, marked by the formation of gibbsitic laterites, ferruginous laterites and bauxitic laterites, respectively."

¹ Louis Kahlenberg and A. T. Lincoln, "Solutions of Silicates of the Alkalies," *Jour. Phys. Chem.*, **II**, 77-90 (1898).

² C. R. Van Hise, "In Treatise of Metamorphism," U. S. Geol. Surv., *Monograph* **47**, pp. 227 (1900).

³ L. L. Fermor, *loc. cit.*; A. La Croix, *loc. cit.*

⁴ F. P. Dunnington, "Distribution of Titanic Oxide upon the Surface of the Earth," *Amer. Jour. Sci. (Silliman's)*, **142**, 491-495 (1891).

Zone of Concretion.—In this zone the leaching is carried to a finish and it is characterized by migration of iron to the surface accompanied by the separation of iron and aluminum hydroxides. The iron sometimes accumulates in sufficient amounts to constitute an iron ore. There are

TABLE I
ANALYSES OF FRESH ROCK AND RESULTING LATERITES

Constituents	Fresh rock nepheline syenite, per cent	RESULTING LATERITE		
		Zone of leaching, porous gibbsitic laterite, per cent	Zone of concretion, compact gibbsitic laterite, per cent	Zone of leaching, clay, gibbsitic, per cent
SiO ₂	56.88	2.21	0.37	35.14
TiO ₂	0.29	0.12	0.90	0.70
Al ₂ O ₃	22.60	55.83	57.12	40.12
Fe ₂ O ₃	0.97	5.22	7.41	4.12
FeO	2.19	....	....	....
CaO	1.33	0.24	0.17	0.45
MgO	0.56	0.19	....	0.21
Na ₂ O	8.30	0.49	0.26	....
K ₂ O	5.57	0.27	0.37	....
P ₂ O ₅	0.08	....	....	....
H ₂ O	0.98	30.47	33.71	17.84
Insoluble	0.34	5.74	0.30	1.46

Constituents	Fresh rock diabase, per cent	RESULTING LATERITE		Fresh rock peridotite, per cent	RESULTING LATERITE	
		Zone of leaching, porous argillaceous gibbsitic laterite, per cent	Zone of concretion, compact gibbsitic laterite, per cent		Zone of leaching, porous argillaceous ferruginous laterite, per cent	Zone of concretion, ferruginous laterite iron ore, per cent
SiO ₂	51.27	5.83	1.30	38.32	12.67	....
TiO ₂	0.70	1.29	1.03	0.28	0.55	....
Al ₂ O ₃	12.36	37.03	60.19	2.66	12.59	4.80
Fe ₂ O ₃	3.29	31.73	3.91	4.35	46.84	83.50
FeO	6.16	....	....	11.78	....	....
CaO	10.66	0.19	0.17	2.74	0.04	....
MgO	13.26	0.06	....	36.22	1.26	....
Na ₂ O	1.60	....	....	0.16	....	....
K ₂ O	0.41	....	....	0.06	....	....
P ₂ O ₅	0.11	....	....	....	....	....
H ₂ O	0.40	23.02	32.00	3.38	15.32	10.18
Insoluble	....	0.96	1.40	....	10.73	1.70

several types of end products resulting from the completion of the process of laterization in the zone of concretion, as described below:

1. **Gibbsitic type:** Chemical analyses and microscopic examination prove that gibbsite migrates nearly as much as does iron hydroxide. Gibbsite is rather soluble in underground waters as is evident from the presence

of this crystalline mineral in geodes and in cracks of laterites and ores from different parts of the tropics. "The final result of the transportation and recrystallization of gibbsite is its formation of granular crystalline rocks of relatively coarse grain composed almost entirely of gibbsite."

2. Ferruginous types: In the laterites derived from peridotites the zone of concretion corresponds with the ferruginous crust. All varieties of limonite, stilpnosiderite, and red tints indicating hematite are seen.

3. Bauxite types: Bauxite types are characteristic of laterites from gneisses, granites and mica schists. The aluminum hydrate, which little by little replaces the aluminum silicate, assumes at first the colloidal form. "It is always accompanied by an important and often prominent proportion of colloidal hydrates" and "this crystalline mineral is a product of transformation of colloidal."

4. Pisolitic laterites: Pisolitic laterites are a very characteristic form. These have been formed *in situ* in a medium in a state of rest, and in general have not suffered transport since their formation. Their form, degree of regularity, and size depend on the physical state of this medium. The best condition for the formation of pisolites is the existence of a homogeneous medium inclosing few or no solid elements unsusceptible of concretionary rearrangement unless in small grains. This explains the abundance of pisolites in the laterite crusts of mica schists, clays and alluvium.

Composition of Laterite Compared with the Parent Rock

La Croix,¹ gives the composition of nepheline syenite, diabase, and peridotite together with the laterites resulting from these rocks.

These figures show that laterites derived from the same kind of rock vary in composition, depending from what zone the analyzed sample is

TABLE II
COMPARISON OF PARENT ROCK AND LATERITES

Constituents	Diabase, per cent	Laterite, per cent	Hornblende schist, per cent	Laterite, per cent
Quartz	3.20	47.35	7.60	32.51
Colloidal Silica	....	0.06	....	....
Combined Silica	47.99	3.30	44.10	14.93
Al ₂ O ₃	15.80	26.33	15.94	34.14
Fe ₂ O ₃	14.28	18.93	14.40	7.64
MgO	5.63	0.21	5.54	0.11
CaO	9.58	0.23	9.60	0.01
Na ₂ O	2.09	0.14	1.87	0.53
K ₂ O	0.60	0.21	0.08	0.48
H ₂ O	0.30	11.28	0.30	9.00
TiO ₂	0.40	0.61	0.30	0.90
P ₂ O ₅	0.008	trace	0.01	0.02
Mn ₃ O ₄	....	....	....	....

¹ L. L. Fermor, *loc. cit.*

taken. The large loss of silica and the persistence of titanium is evident. There is an enrichment of aluminum and iron in all cases, but where the enrichment of iron is large, that of aluminum is correspondingly small. The greater part of the alkalis and alkaline earth disappears in the process of laterite formation. A large enrichment in aluminum is followed by a large degree of hydration, and when iron predominates over the aluminum the degree of hydration is less.

Harrison¹ gives the composition of some laterites from British Guiana, together with the parent rock. See Table II.

In these laterites a large amount of quartz is present apparently in a free condition. While the chemical process of laterization sets silica free, it does not necessarily remove the silica from the laterite. Whether silica shall be removed seems to depend on the mode of motion of the water.

Composition of Various Laterites

Warth and Warth² give the composition of a number of Indian laterites which they divide into four groups as follows: 1. Laterites which are very low in iron, very high in aluminum and have a very small amount of quartz. 2. Those which are very high in aluminum, have more iron than those in group 1, while the amount of quartz is the same. The laterites in this group are called bauxites. 3. Laterites whose alumina content ranges from 54.8 to 26.3 and whose iron oxide content ranges from 17.75 to 56.00% but whose quartz content is the same as that of groups 1 and 2. These are called "laterites *in situ* which are bauxites." 4.

TABLE III

COMPOSITION OF INDIAN LATERITES²

Constit- uents	Group 1 per cent	Group 2, per cent	Group 3, per cent	Group 4, per cent
H ₂ O	33.74	26.47	26.94	26.82
Quartz	...	...	...	...
SiO ₂	2.78	.93	2.35	3.90
TiO ₂	.04	1.04	6.61	.38
CaO	.20	.36	0.15	.35
MgO	.03	....	...	.20
Fe ₂ O ₃	.44	4.09	6.53	13.75
Al ₂ O ₃	62.80	67.88	57.50	54.80

Detrital laterites. In these the iron content is greater than that of aluminum and the amount of quartz ranges from 6.67 to 39.53%. In Table III are given the composition of representatives from these groups. Combined silica is designated as SiO₂ while free quartz is given under that heading.

¹ J. B. Harrison, *loc. cit.*

² H. Warth and F. J. Warth, *loc. cit.*

These figures show the wide range in composition of laterites. The iron and aluminum bear to each other a somewhat reciprocal ratio; when one is high the other is likely to be low. The degree of hydration is usually greater in the highly aluminous laterites, and correspondingly low in the highly ferruginous.

Laterites from Madagascar

Baur¹ gives a number of analyses of laterites derived from different rocks in Madagascar. See Table IV.

TABLE IV

COMPOSITION OF LATERITES FROM MADAGASCAR DERIVED FROM THE VARIOUS KINDS OF ROCK

Constituents	Granite, per cent	Diabase, per cent	Amphibole, per cent	Sandstone, per cent
Insoluble	3.32	3.78	15.79	75.38
Soluble SiO ₂	1.29	14.17	6.98	0.50
Al ₂ O ₃	60.86	44.87	43.37	12.87
Fe ₂ O ₃	1.00	17.33	13.04	2.34
CaO	...	0.18	0.03	...
MgO	...	0.13	trace	trace
H ₂ O	33.42	20.06	21.78	9.51

Relationship of Laterite and Bauxite

It was noted in discussing the meaning of laterite, that there was nothing in the various terms used to describe laterite which would exclude bauxite. Warth and Warth² are very definite on this point in that they class certain laterites as bauxites. Lemoine and Chautard³ state that the practical result of laterization is the deposition of bauxite. La Croix,⁴ does not regard bauxite as a mineral because it does not have a constant composition; in France it approaches Al₂O₃.H₂O; in Arkansas Al₂O₃.3H₂O. Bauxite is a rock composed of various aluminum hydrates, mixed with ferric hydrate, clay and other impurities. Fermor⁵ in dividing the bauxites of India into high-level and low-level laterite classes the bauxites with the high-level laterites, but not all high-level laterites are bauxites.

Baur¹ has shown that the laterites of the Seychelle Islands consist principally of hydrargillite and in this respect there is no difference between laterite and the bauxites of Vogelsberg and other places. Both are products

¹ Max Baur, *loc. cit.*

² H. Warth and F. J. Warth, *loc. cit.*

³ Paul Lemoine and Jean Chautard, "The Phenomena of Laterization," *Bull. Soc. Geol. France*, 4 [8], 55-8; *C. A.*, 3, 298 (1909).

⁴ L. L. Fermor, *loc. cit.*; A. La Croix, *loc. cit.*

⁵ L. L. Fermor, *loc. cit.*

of changes in aluminous minerals. Fox¹ has made a special study of the bauxite resources of India, and he concludes that bauxites occur only in association with the oldest laterites. In the formation of bauxite the softer ferruginous matter has been broken up and washed away, leaving the hard boulders of aluminous matter behind. Mead² divides the bauxites of Arkansas into two classes: (1) bauxites, in place and (2) bauxites, transported and detrital. The first is a residual product of the surface

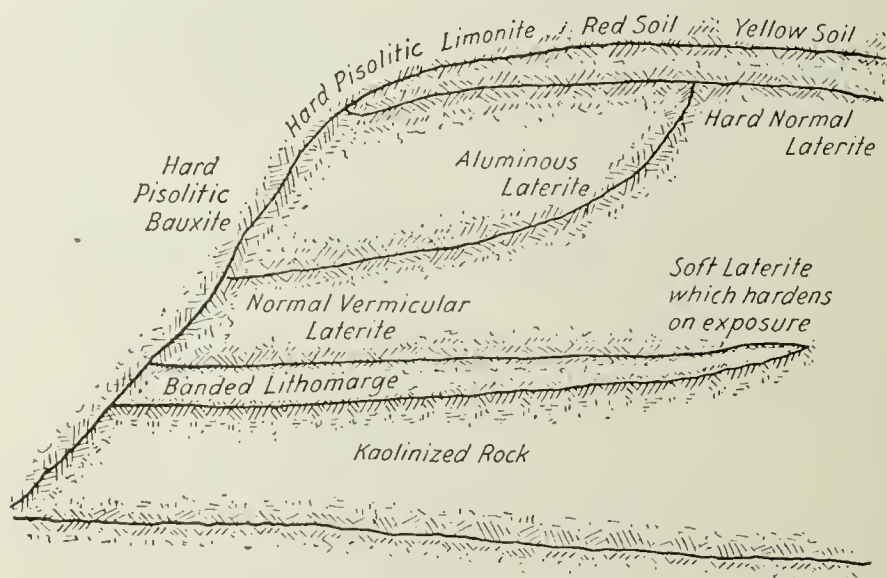


FIG. 1.

weathering of syenite. It grades downward into kaolin which in turn grades into syenite. The second represents material which was carried from the original position by streams during tertiary times.

Bauxite has about 38% pore space and open texture is essential for its formation. In this respect

the conditions for the formation of bauxite and laterite are similar. The alteration of clay to bauxite is accomplished through the agency of circulating solutions, which suggests that the stability of some clay is due to its imperviousness and that only open textured clay can be altered to bauxite.

Fox¹ gives a diagram which illustrates the relation between laterites and some bauxites. (See Fig. 1.)

The similarity in composition of bauxites and laterites is shown in the following tables:

TABLE V
CHEMICAL COMPOSITION OF UNALTERED SYENITE AND BAUXITE ORE OF ARKANSAS³

Constituents	Unaltered syenite, per cent	Bauxite ore, per cent
SiO ₂	58.00	10.64
Al ₂ O ₃	27.10	57.48
Fe ₂ O ₃	1.86	2.56
FeO	3.30	.20
MgO	.25	...
CaO	1.62	...
Na ₂ O	6.70	...
K ₂ O	.25	...
TiO ₂	.40	1.20
H ₂ O	1.20	28.36

¹ Cyril Fox, *loc. cit.*
² W. J. Mead, *loc. cit.*

TABLE VI

COMPOSITION OF BAUXITE OF ALABAMA AND ARKANSAS¹

Constituents	Arkansas		Alabama	
	White, per cent	Red, per cent	White, per cent	Red, per cent
SiO ₂	10.00	4.00	2.38	8.16
Al ₂ O ₃	52.00	53.00	61.87	53.87
Fe ₂ O ₃	4.00	10.00	.40	4.52
TiO ₂	4.00	4.00	...	...
H ₂ O	30.00	29.00	30.50	24.86

TABLE VII

COMPOSITION OF BAUXITES FROM VARIOUS COUNTRIES²

Constituents	France		Hungary, per cent	Italy, per cent	United States, per cent	British Guiana, per cent
	A, per cent	B, per cent				
SiO ₂	0.80	0.29	0.80	2.79	2.90	2.73
TiO ₂	3.50	0.80	2.80	1.27	3.40	0.10
Al ₂ O ₃	76.40	60.60	65.50	57.60	58.21	64.38
Fe ₂ O ₃	4.80	26.00	21.30	28.55	3.60	0.50
CaO	...	...	...	...	...	...
MgO	...	...	...	...	...	...
H ₂ O	14.3	10.4	9.96	11.71	31.89	32.29

Summary

The term laterite means a red rock or red earth deposit. If bauxites are a species of laterite, then it may be said that scattered deposits of laterite are found in higher latitudes. The prevailing compounds in laterite are aluminum and iron hydroxides, found in somewhat reciprocal amounts. Silica is present mostly as free quartz in those laterites which have suffered transport since formation. Some laterites are very rich in aluminum hydroxide, others in iron hydroxide, still others are rich in free quartz and a variety of compounds; all are low in alkalis and alkaline earths. All red earths are not necessarily laterites.

Some laterites are classed as high-level laterites. These are formed *in situ* and are the purest. Others are classed as low-level laterites. These have usually suffered transportation since formation, and during this process have become mixed with various materials such as clay and quartz. Then there is laterized alluvium as well as variations between these classes. The upper surface of a laterite deposit often has a hard crust.

Laterites may be formed from a variety of rocks. Igneous rocks, particularly granites and gneisses, are the usual source. The process of laterization, and the modifications since formation have more to do with the character of the laterite formed than has the nature of the parent rock.

The hot, moist climate of the tropics, particularly the alteration of wet

¹ T. L. Watson, *loc. cit.*

² Cyril Fox, *loc. cit.*

and dry seasons, appear to be favoring conditions for the formation of laterite and necessary for the accumulation of extensive deposits. Laterite formation is probably as prevalent in the tropics as residual clay formation in the higher latitudes. One theory places microorganisms as the chief agents in laterite formation. One condition for the life of these organisms is a continuous warm climate.

The process of laterite formation, consists in the elimination of alkalies, alkaline earths, and silica from the original rock and the accumulation of the hydrated oxides. Physically it is necessary that the rock or earth undergoing laterization shall remain porous in order that the minerals in solution may pass from below upward, and also that there shall be surface drainage to carry away minerals in solution. Laterites are not formed where the water stands continuously. The destruction of capillaries by frost is given as one reason why laterites do not form in higher latitudes. In the formation of kaolin, two-thirds of the silica present in the feldspar is set free; in the formation of laterite, all the silica is set free.

Laterites may be so rich in aluminum hydroxide that they serve as an ore of aluminum. In such a case they are bauxites. They may also be so rich in iron hydroxide that they serve as iron ores. From this standpoint they are also of great economic importance.

NOTE:—The writer desires to express his appreciation to Dr. H. Ries of Cornell University for suggesting this study and for helpful assistance in preparing the manuscript.

Appreciation is also expressed to Professor T. L. Watson of the University of Virginia for reading the manuscript and giving constructive criticism.

METHOD FOR ANALYZING DIASPORE CLAY

By M. H. THORNBERRY

ABSTRACT

The method of analyzing refractories recommended by the A. S. T. M.¹ having proved unsatisfactory for diaspore clays, a change has been made whereby fusion is accomplished by adding c. p. NaOH instead of Na₂CO₃ to the finely ground clay and the mixture heated in a nickel crucible over a bunsen burner.

The primary object of this article is an outline and discussion of the method used by the State Mining Experiment Station of the Missouri School of Mines and Metallurgy for the analysis of diaspore clay, but we feel that a few words of explanation relative to this special variety of clay will not be out of place before taking up the method for analysis.

Dana gives the following description of diaspore: fracture conchoidal, very brittle. Hardness 6.5–7. Gravity 3.3–3.5. Luster brilliant; pearly on cleavage face, elsewhere vitreous. Color whitish, grayish white, greenish gray, hair brown, yellowish to colorless. Composition AlO(OH) or Al₂O₃.H₂O. Alumina 85.0, water 15.0 = 100.

Diaspore clay at the present time is found in commercial quantities in Franklin, Casconade, Osage, and Phelps counties, Missouri. Prior to 1917 this clay was thrown aside as refuse. In January, 1917, W. S. Cox, Cuba, Mo., sent the writer a sample of this clay for analysis. As far as our knowledge goes Dr. Cox was the first operator to see the value of this material and should be given credit as the discoverer of diaspore clay in Missouri.

The writer has analyzed hundreds of samples of this variety of clay. A few complete analyses are listed below:

	Sample A	Sample B	Sample C	Sample D	Sample E
Silica (SiO ₂).....	11.04	3.88	10.24	7.64	15.96
Alumina (Al ₂ O ₃).....	70.72	76.07	70.04	68.11	62.38
Iron Oxide (Fe ₂ O ₃).....	1.57	3.03	2.29	6.05	3.41
Lime (CaO).....	None	None	None	None	None
Magnesia (MgO).....	None	None	None	None	None
Titanium (TiO ₂).....	3.11	4.14	4.19	4.13	3.87
Soda (Na ₂ O).....	0.08	0.06	0.08	0.10	0.23
Potash (K ₂ O).....	0.17	0.11	0.19	0.16	0.31
Ignition Loss.....	13.42	13.06	13.13	13.47	13.41
Total.....	100.11	100.35	100.16	99.66	99.57

The Missouri State Mining Experiment Station has been using for a number of years practically the same method for analyzing refractories as outlined in the *Proceedings of the American Society for Testing Materials*.¹ The carbonate fusion² was tried time after time for diaspore

¹ *Proc. A.S.T.M.*, 628–38 (1921).

² *Ibid.*, 630.

clays. The amount of flux, temperature, and time were varied but without success. In all cases a black, gritty, insoluble residue remained after treating the melt with acid. After repeated unsuccessful attempts to fuse the clay in this manner a method was worked out which has given complete satisfaction. The procedure of the method is practically identical with the one mentioned above, the only difference being the fusion.

Procedure of Method

Weigh 0.5 gram of the finely ground clay and transfer to a nickel crucible. (We find that a crucible $1\frac{3}{4}$ inches high and $1\frac{5}{8}$ inches in diameter is best suited for this work.) Add about $\frac{3}{4}$ inch of c. p. NaOH stick. (Care should be taken at this point because even some c. p. NaOH contains alumina.) Moisten with distilled water. Cover and heat gently over a blue flame of a bunsen burner until ebullition has ceased. Continue heating until the fusion is quiet and the lower half of the crucible is a dull red. Pour fusion on a nickel lid used for that purpose. Dissolve portion of fusion remaining in crucible and on its lid with hot water, transferring to a platinum dish or casserole, to which is added the melt from the other nickel lid. Add water until volume is about 100 cubic centimeters. Add about 20 cubic centimeters of concentrated HCl, keeping dish covered with a watch glass. Evaporate to dryness. The method from this point is practically identical with that as outlined in the bulletin mentioned, hence, no further discussion is necessary.

The advantage of this method is a complete fusion in a very short time. A sample can be weighed, fused, and prepared for evaporation in seven minutes.

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THE ANALYSIS OF REFRACTORIES

BY C. A. UNDERWOOD

ABSTRACT

Methods for use in the analysis of refractories are described, including the preparation and solution of the sample and the determination of the content of silica, alumina precipitate, iron, titanium, alumina, lime, magnesia, and alkalies.

Introduction

The purpose of this paper is to set forth, in a general way, the methods used in the analysis of refractories. In this class of materials, as in others, there are precautions to be taken. Considerable time is required for the analyses, and the attempt to take short cuts often results in errors which would otherwise be avoided. It is also important to get the right start. Refractories are resistant to acids and often require strong fluxes to decompose them.

Preparation of the Sample

The method of taking a certain proportion of the whole, and quartering down applies to this class of work as it does to others. Very often it is simply a matter of judgment because no standard exists. However, it is well to remember in sampling bricks that only the inside portion should be taken. Silica brick, for instance, are sprinkled with sand during molding and setting, and the inclusion of the skin in the sample will affect the analysis.

The crushing is usually done in a small laboratory jaw crusher, but the pulverizer attachment is never used. There are cases where the iron content of dead-burned magnesite has been doubled by the use of the pulverizer. In its place a hardened steel mortar and pestle are used; the sample being pulverized to pass a 100-mesh screen by repeated crushings. It also might be mentioned that silica brick and ganister samples are treated with a magnet before proceeding with the analysis.

Solution of the Sample

Silica brick, ganister, magnesite and fire clays are all decomposed by fusion with sodium carbonate. After the melt has cooled it is treated with dilute hydrochloric acid and gently heated until all but the silica has gone into solution.

Diaspore, bauxite, spinel and chrome ore must be fused with potassium pyrosulphate. In the case of crude diaspore, it is desirable to drive off the combined water before making the fusion. Otherwise the substance floats on the fusion and is not attacked. A good way to proceed in this case is to determine the "loss on ignition" first and use a part of the ignited portion for the analysis.

Fine grinding in an agate mortar facilitates the decomposition of this class of materials. The pulp is usually ground until no gritty particles are felt when rubbed on the palm of the hand.

Silica

After the melt has been dissolved with hydrochloric acid the solution is transferred to an evaporating dish and evaporated to dryness on the water bath. When dry, the residue is baked at 120°C in a drying oven until all traces of acid have been expelled. It is then moistened again with dilute hydrochloric acid, evaporated and baked the second time. The residue is then dissolved in dilute hydrochloric acid and water and silica filtered off.

In the case of diaspore, bauxite, and spinel, dryness cannot be accomplished on the water bath alone. To attain this condition the evaporating dish is supported about two inches above the hot plate, placing sufficient asbestos padding beneath the dish to prevent heating too rapidly. It is not necessary to repeat the baking in this case.

The silica is purified with hydrofluoric acid on clays, diaspore, bauxite, spinel and chrome. The residue which is composed principally of iron, alumina and titania is fused with potassium pyrosulphate and added to the filtrate. On magnesite, silica brick and ganister the impure silica is reported. It has slight amounts of the impurities mixed with it but this is compensated by the small amounts of silica passing into the filtrate and which will be precipitated with the iron and alumina. This practice appears to be crude on first thought but it has been demonstrated in the course of many analyses that one error very nearly compensates the other. In fact, so much so that for commercial analyses, the practice has become general.

Some methods advanced for the analysis of magnesite, call for direct decomposition with hydrochloric acid. After the ore has been decomposed, the solution is evaporated to dryness and baked. The impure silica is purified with hydrofluoric acid and this result reported. It might be mentioned that on dead-burned magnesite, fairly uniform results are obtained by this method. The silica, however, will be 0.70% lower than the actual amount of silica present. By comparing the silica obtained by the sodium carbonate method with that obtained by an ultimate analysis, it can be shown that the silica content will be less than 0.30% low. Furthermore, the direct acid treatment cannot be successfully employed on crude magnesite.

Alumina Precipitate

By the addition of ammonia, alumina is precipitated together with iron, titanium, chromium, manganese, zirconium and phosphorous oxides.

The latter three constituents are rarely ever determined in commercial work. For magnesite, silica brick and ganister only one precipitation is made. Two precipitations are sometimes recommended for magnesite but if the solution is not too concentrated and if the ammonia is added a little at a time, good results can be obtained. Only a slight excess of ammonia should be used and the washing done with dilute ammonium nitrate solution.

Where potassium pyrosulphate is used to decompose a sample, weighable amounts of platinum are dissolved from the crucible. It is necessary to remove this by passing hydrogen sulphide through the solution. The platinum sulphide is filtered off and the iron reoxidized with bromine water before proceeding with the alumina precipitation. This procedure consumes considerable time and can be avoided in general work by weighing the crucible before and after the fusion. The loss in weight is then deducted from the weight of the alumina precipitate.

For chrome, diaspore, clay, etc., two precipitations in dilute solutions are necessary. The heavy precipitates in this class of substances adsorb large amounts of alkalies, which can only be removed by a second precipitation and thorough washing. It is a good plan to transfer the precipitates to the filter and wash five times, breaking up the precipitates with the stream from the wash bottle.

Either rosolic acid or methyl red is used as an indicator and great care should be exercised in following the color change. Hot dilute ammonium nitrate or chloride should be used for the washings, otherwise small amounts of the alumina will pass into the filtrate.

Iron

Iron is usually reported as Fe_2O_3 except in the case of chrome ore where it occurs principally as FeO . Chrome ore contains both oxides as a rule but in technical work the determination of the ferrous oxide is seldom made.

In diaspore, clay, etc., where titanium is present in appreciable amounts, hydrogen sulphide is employed as the reducing agent. In silica brick, ganister, magnesite and chrome, titanium is usually present in very small amounts and in these substances the iron may be reduced with zinc. This distinction is made because zinc reduces the titanium as well as the iron, thus giving high results. $N/25$ potassium permanganate is used in the titration; a 500 cubic centimeter Erlenmeyer flask being employed for both the reduction and the titration.

Titanium

Titanium is determined by the colorimetric method, the solution used for the titration of iron being best adopted for this purpose. There are

many precautions to be taken. The procedure is described in detail in the text books so that it is unnecessary to go into it here.

Alumina

The percentage of alumina is obtained by deducting the iron and titanium from the total "alumina precipitate."

Lime

The determination of lime in silica brick, ganister and clays offers no difficulty. After precipitating with ammonium oxalate and ammonia the solution is allowed to evaporate to 150 cubic centimeters. During this time the calcium oxalate will settle completely. It is then filtered and titrated with $N/25$ potassium permanganate.

In diaspore, spinel, and chrome the precipitation is carried out in the same way except that it is allowed to stand over night. It has been found that where large amounts of alkali sulphates are present, the calcium oxalate does not precipitate as readily as when they are absent. Hence, the longer time allowed for complete precipitation. The next morning the calcium oxalate is filtered off, redissolved with dilute hydrochloric acid, and precipitated the second time. It will now settle quickly and be entirely free from magnesium salts.

The determination of lime in magnesite is subject to a considerable error owing to the large amount of magnesium present. Various methods have been proposed but sufficient work has not been done to settle this question. A method which has found considerable use is given here.

To the cold filtrate from the iron and alumina precipitation, add 10 grams of ammonium chloride (if it has not already been added before the iron and alumina precipitation), 40 cubic centimeters of concentrated ammonium oxalate and 1 or 2 cubic centimeters of ammonia. Stir and allow to stand over night. Filter off the precipitate and wash not more than once or twice. Redissolve into the original beaker, add 10 grams of ammonium chloride, a few cubic centimeters of ammonium oxalate and a few drops of methyl orange. Heat to boiling and precipitate with ammonia. Bring just to boil and allow to settle hot for one and one-half hours. Filter and wash slightly as before. Redissolve in hydrochloric acid and make a second hot precipitation. Allow to stand as before and filter. Wash six times with hot water and titrate with potassium permanganate. The procedure in general is one cold and two hot precipitations. The volumes should be from 400 to 500 cubic centimeters.

Magnesia

The determination of magnesia is discussed thoroughly in the text-books and nothing need be added here. It might be mentioned that two pre-

precipitations are desirable, especially where the magnesia is high and large amounts of fixed alkalies are present. In the technical analysis of magnesite and dolomite, the magnesia is usually determined by difference. This procedure saves much time and is sufficiently accurate for most purposes.

Alkalies

Potash and soda are determined by the J. Lawrence Smith method.

Conclusions

The correct summation of analyses is an important consideration and affords a good indication of the quality of the work.

In commercial analyses, chrome ore might be said to be an exception. Only the total oxides of iron are determined, as a rule, and reported as FeO . However, there may be several per cent of the iron present as Fe_2O_3 and unless both oxides are determined separately there is no way of knowing how to report the analysis. Again the "ignition loss" gives low results as compared to the actual determinations of combined water. This discrepancy may be considerable since there is a tendency for the ferrous oxide to be oxidized to ferric oxide. Hillebrand states: "Loss on ignition with carbonate rocks represents, as with those of a silicate nature, the algebraic sum of a number of chemical changes involving both losses and gains, and its amount will depend largely on the temperature employed."

Clays offer no difficulty in obtaining a summation of 100 to 100.50%.

Diaspores can be made to total under 100.50% but all the refinements must be exercised.

Magnesite is difficult to bring within reasonable limits when the MgO content is actually determined, especially is this the case with calcined magnesite. An aliquot part must be taken and a second precipitation made to eliminate the alkalies present. A small plus error will be multiplied many times in calculating the per cent.

Silica brick and ganister will total between 100 and 100.20%. Usually only the silica, iron, alumina and lime are determined and in this case, the summation ranges from 99.60 to 99.85%.

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MEASUREMENT OF THE HEAT ABSORBED AND EVOLVED BY CLAYS DURING FIRING AND COOLING¹

BY LOUIS NAVIAS

ABSTRACT

Apparatus.—A vacuum calorimeter containing an insulated platinum resistance furnace is described for use in determining reaction heats, and the heat absorbed in raising the temperature of a material in the furnace from room temperature to 1200°C, and also the heat evolved in cooling down the material from 1200°.

Materials experimented with.—Four typical clays are employed, namely A-1 English china clay, North Carolina kaolin, Tennessee ball clay No. 5, and Laclede-Christy raw flint clay. The calorimeter is calibrated with pure quartz.

Results.—The numerical data obtained are assembled in Table IV. The quantity of heat absorbed per gram per degree on heating the air dried clays over the complete temperature range 25–1200° amounts to 0.50–0.55 calories, whereas the heat evolved on cooling the final products per gram per degree through the range 1200–700° is 0.23–0.29 calories.

The heat absorbed in the ranges 24–420°, 420–900°, and 900–1200°, together with the heat evolved in the ranges 1200–900°, and 900–700°, are also given for all of the above clays.

I. Introduction

1. **Purpose of the Investigation.**—When refractory materials are fired, heat is absorbed, the net quantity depending upon the specific heats and upon the heats of reaction resulting from chemical and physical changes in the constitution of the fired material. Exothermic reactions help to raise the temperature of the materials whereas endothermic reactions require an additional amount of heat to complete them, before the temperature can again rise. In materials like clays, and in bodies containing them, these reactions are quite often not reversible, meaning that the heat absorption on firing is not equivalent to the heat evolution on cooling. It is impossible then, with such materials to obtain the heat absorption on firing by the method of mixtures, which is the usual method employed for determining specific heats.

In the method of mixtures, the substance is heated to a high temperature, and the resulting heated material is dropped into a calorimeter, and the heat evolved by the material measured by the increase in temperature of the calorimeter bath. The present investigation has primarily for its purpose the measurement of the heat energy required to raise the temperature of raw clays, from room temperature to 1200°C, by a method and apparatus devised for the work. An experiment is run continuously on one sample to the highest temperature, and the heat absorption is measured

¹ This paper is an abstract of a thesis presented to the graduate school of the University of Illinois in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Ceramic Chemistry, in February, 1923.

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for three separate ranges of temperature; then the energy source is cut off, and the heat evolved by the fired material as it cools to 700° is measured over two ranges of temperature.

All temperatures given in this paper are in degrees centigrade.

2. Data in Literature on Specific Heats of Minerals, Refractories and Clays.—These are all data on materials experimented with by the method of mixtures.

(a) *Minerals*. White¹ obtained the Interval Mean Specific Heats on the silica minerals, quartz and cristobalite, on the feldspars, anorthite, andesine, albite, microcline, and on other natural minerals as pseudowollastonite, and on some of the natural forms of magnesium silicate. White also worked with some of the glasses of the above materials. His range of temperature was from room temperature to 1400° . From the data, he calculated the true instantaneous specific heats at different temperatures. His data will be referred to later.

Wietzel² found the Interval Mean Specific Heats of cristobalite, quartz, chalcedony and silica glass up to 1400° . The data on quartz and cristobalite are discussed in a later chapter.

(b) *Refractories*. Bradshaw and Emery³ have obtained the Interval Mean Specific Heats on some refractory materials up to 1400° . Table I gives their results in calories per gram from t° to 25° .

TABLE I

INTERVAL MEAN SPECIFIC HEATS OF REFRACTORY MATERIALS t° TO 25°

t°	Silica brick	Fire brick	Pure zirconia	Stourbridge fire brick
600	0.226–8	0.228	0.137	0.227
1000	.263–2	.265	.157	.263
1200	.282–3	.284	.167	.262
1400	.293–5	.297	.175	...

Tadokoro⁴ experimented with different types of brick to 900° . The Interval Mean Specific Heats in calories per gram from t° to 30° are given in Table II.

Moore⁵ worked with a terra cotta body that had been burned to 1100° . In cooling from t° to 0° , when t° is equivalent to 500° , 700° and 900° , the Interval Mean Specific Heats in calories per gram are 0.235, 0.245 and 0.249, respectively.

¹ W. P. White, *Amer. Jour. Sci.*, **47**, 1–43 (1919).

² Rudolf Wietzel, *Z. anorg. allgem. Chemie*, **116**, 80 (1921).

³ L. Bradshaw and W. Emery, *Trans. Ceram. Soc. (Eng.)*, **19**, 84–92 (1919–20).

⁴ Yoshiaki Tadokoro, *Sci. Repts. (Tôhoku Imp. Univ.)*, **10**, 339–410 (1921).

⁵ J. K. Moore, "Tests on the Thermal Conductivity of Terra Cotta Fireproofing," Thesis for B.S. Univ. Ill. (1908).

TABLE II

INTERVAL MEAN SPECIFIC HEATS OF BRICK, t° TO 30°

t°	Magnesia	Red clay	Silica	Chrome	Shamotte
218	0.223	0.207	0.199	0.178	0.197
303	.238	.221	.218	.195	.209
382	.254	.239	.233	.210	.222
480	.263	.247	.246	.216	.238
579	.266	.249	.249	.221	.251
687	.265	.247	.250	.219	.255
796	.264	.242	.247	.218	.249
894	.263	.237	.242	.215	.241

(c) *Clays*. Knoté¹ determined the specific heat of a flint clay from Olive Hill, Kentucky, from 150° to 22° . The raw clay had a specific heat of 0.237, the clay burned to 650° , a specific heat of 0.204, and when burned to 1050° , a specific heat of 0.200.

3. **Method, General Description.**—The method employed consisted of immersing in a thermostat at room temperature a small vacuum jacketed furnace containing the sample of material to be investigated. The furnace was heated electrically by means of a platinum heating coil and the energy supplied in this way was accurately measured by means of a recording wattmeter. A thermocouple was inserted in the center of the charge for reading its temperature. The whole furnace was encased in a nickel cylinder which was evacuated, the whole being immersed in the water of the stirred bath.

During the passage of the heating current, some of the energy supplied to the furnace leaked out through the nickel containing cylinder into the water of the bath. This tended to raise its temperature above that of the room. In order to prevent this and to measure the energy which leaked out in this way, ice water was admitted to the bath at such a rate as to keep its temperature practically constant. An equivalent amount of water from the bath overflowed and was collected in a container for weighing. When, with a given heating current, the temperature of the center of the charge became constant and remained so for some time, this temperature was read and the container which received the overflowing water was removed and replaced by a second container. The heating current was then immediately raised to the second level and the above procedure repeated, as soon as the temperature of the center of the charge had again become constant at the higher value.

By weighing the water which overflowed from the water bath, the amount of energy which leaked out of the furnace through each stage could be accurately computed. From the record of the wattmeter, the amount of energy sent into the furnace could be similarly accurately

¹ J. M. Knoté, *Trans. Amer. Ceram. Soc.*, 14, 394–8 (1912).

computed. The difference between these two amounts obviously represents the heat absorbed by the charge and the furnace parts. The heat was measured with an accuracy of about 1% in the present investigation.

In order to determine the amount of heat absorbed by the furnace parts during the operation, the same series of experiments was repeated, using in place of the charge of clay a charge consisting of a known weight of quartz whose specific heat curve up to high temperatures has been accurately determined. In this second series of experiments, the heat absorbed by the charge is known and by subtracting this from the total heat absorbed by the furnace plus the charge, the heat taken up by the furnace parts could be computed. By combining this value with the results obtained when using the various clays in the furnace, the heats absorbed by the clays themselves can obviously be calculated. It is estimated that this heat was measured with an accuracy of about 10%.

It was found expedient to limit the temperature ranges to approximately 24–420°, 420–900°, 900–1200° for ascending temperatures, and 1200–900°, 900–700° for descending temperatures.

4. Available Specific Heat Data for Calibrating the Calorimeter.

The only data that are given on pure materials and over the complete range of temperatures from 0° to 1400° are those furnished by the experiments of White¹ and Wietzel.² The list of materials contains feldspars and magnesium silicates, which however are difficult to obtain with theoretical compositions. The glasses of these minerals crystallize fairly easily, which decreases their value for calibration purposes. The only other materials that can be considered are, then, quartz and cristobalite, data being furnished by both experimenters. Figures 1 and 2 give the complete data.

It will be noticed that the data on the quartz are much more concordant than are the data on the cristobalite. Wietzel has shown, as have others,

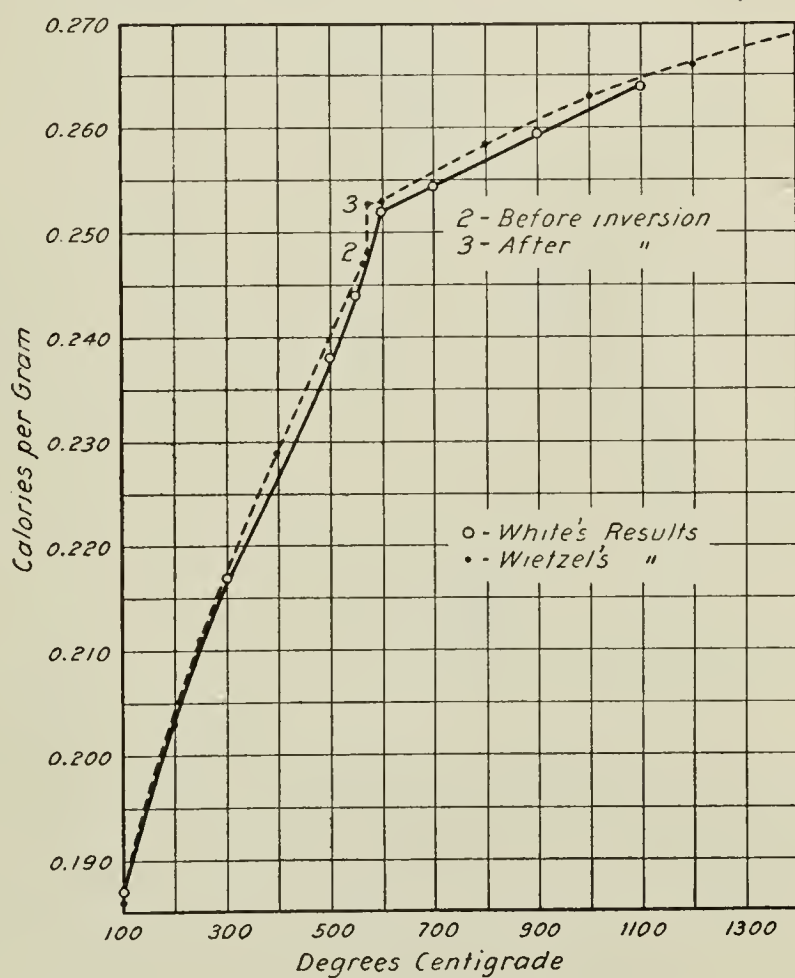


FIG. 1.—Average specific heats between 0° and t° of quartz.

¹ W. P. White, *loc. cit.*

² Rudolf Wietzel, *loc. cit.*

as Washburn and Navias,¹ that the physical properties of cristobalite depend on the previous history of the material, that is, of preparation and of the extent of calcination.

For quartz, White gives values only up to 1100°, whereas Wietzel gives them as high as 1400°. In a preliminary run of the present investigation, crushed quartz heated to 1400°, in eight hours, gave inversion

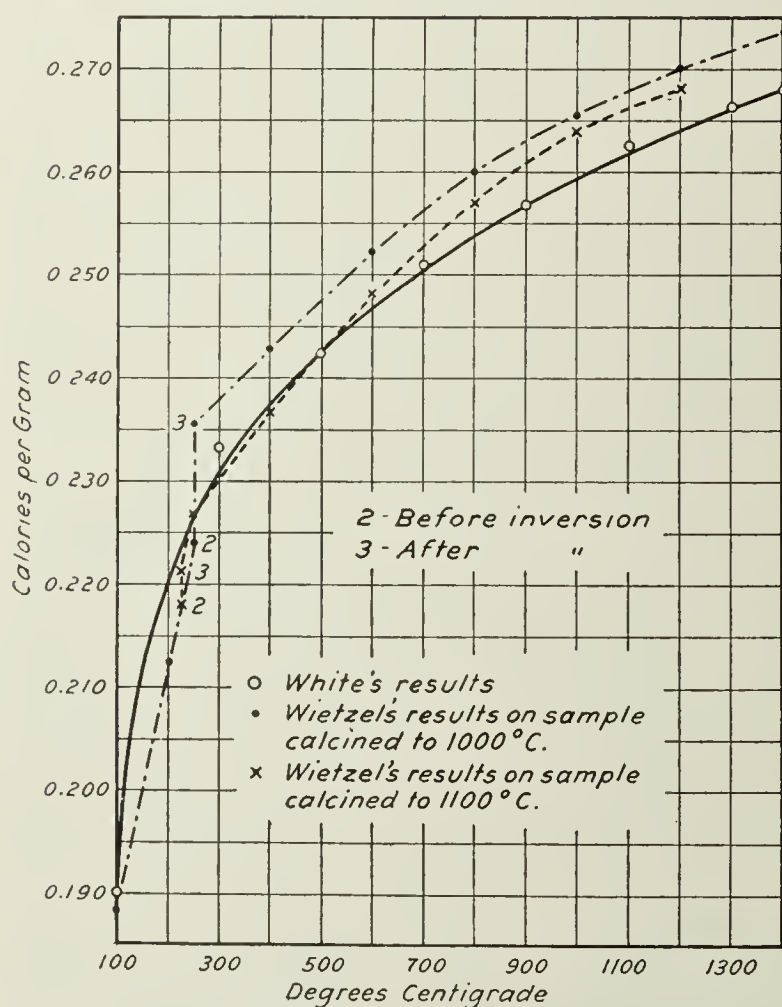


FIG. 2.—Average specific heats between 0° and t° of cristobalite.

to cristobalite of about one quarter of the material. In two regular runs, quartz heated to 1200°, in ten hours each, gave no trace of inversion. This was determined by measuring the index of refraction of the grains. As the maximum temperature to be attained safely in the calorimeter is 1200°, quartz may be used to advantage. By adding Wietzel's result at 1200° to those of White's at lower temperatures, the data are complete for application to the present problem. As the work of White has extended over many years and with concordant results, preference has been given to his work.

II. Heats of Reaction of Clays at High Temperatures

5. Clays Experimented with.—The clays experimented with are typical of the different kinds used in the industries. Unfortunately the choice had to be limited to the purest clays, on account of the conditions under which the experiments were made. Attempts to experiment with brick clays and the like, have resulted in wrecking of the furnace, due to the bloating of the clays. The chemical analyses of the clays are given in Table III.

6. Reactions in Clays Due to Heating.—Mellor and Holdcroft,² working with kaolinite, determined from their time-temperature curves ob-

¹ Edward W. Washburn and Louis Navias, *Jour. Amer. Ceram. Soc.*, **5**, 565–85 (1922).

² J. W. Mellor and A. D. Holdcroft, *Trans. Ceram. Soc. (Eng.)*, **10**, 94–120 (1910–11).

TABLE III
CHEMICAL ANALYSES OF THE CLAYS EXPERIMENTED WITH

	(1) Per cent	(2) Per cent	(3) Per cent	(4) Per cent
SiO ₂	45.20	45.2	45.60	43.70
Al ₂ O ₃	38.45	38.8	35.90	39.38
Fe ₂ O ₃	0.45	0.3	1.00	0.79
TiO ₂	trace	trace	1.00	1.95
CaO	trace	0.9	0.10	0.10
MgO	trace	.8	.30	.37
Na ₂ O	0.00	2.1	.46	trace
K ₂ O	.65		.72	
H ₂ O	14.80		...	....
Ign. loss	...	12.5	14.60	14.08
	99.55	100.6	99.68	100.37

- (1) North Carolina kaolin (Harris Clay Co., Sprucepine).
- (2) A-1 English china clay (Hammill and Gillespie).
- (3) Tennessee ball clay No. 5 (Mandle Clay Mining Co.).
- (4) Laclede-Christy raw flint clay (Missouri).

tained by a differential thermal method and from other experiments the following results:

- (1) Just above 500°, heat is absorbed by an endothermic decomposition of kaolinite into free silica, free alumina and water. Graphically the “latent heat of decomposition” is calculated to be 42 calories per gram of raw clay.
- (2) At approximately 800°, in the heating curve, there is an exothermic change shown corresponding with a physical change of the free alumina, whereby the alumina becomes less soluble in acids, less hygroscopic and more dense. The “latent heat of transformation” is determined graphically to have the value of 21.5 calories per gram.
- (3) The formation of sillimanite in kaolinite when heated over 1200° is due to the recombination of the free alumina with some free silica formed at about 500°.

Wallach,¹ by a differential thermal method, has shown that kaolin, clays, mica and glauconite absorb heat when dehydrated between 450° and 600°, and evolve heat between 900° and 1000°. According to Le Chatelier the evolution of heat is due to a transformation of the alumina. Wohlin² substantiates the above results by a similar method. In clays, between 560° and 580°, there is an endothermic reaction, at 960° the reaction is exothermic. Bauxite, Al₂O₃.H₂O, has an endothermic reaction at 540°, while bauxite Al₂O₃.3H₂O has an endothermic reaction at 310°—both having exothermic reactions at 1060°.

Zoellner³ heated clays to high temperatures and then disintegrated the products in hydrofluoric acid. The residue consisted of sillimanite crystals. He determined that cone 10 (ca. 1300°) had to be reached before

¹ Ruby Wallach, *Compt. rend.*, **157**, 48–50 (1913).
² R. Wohlin, *Sprech.*, **46**, 719–21, 733–5, 749–51, 767–9, 780–2 (1913).
³ Zoellner, *Brit. Clayworker*, **22**, 40 (1913).

sillimanite could be obtained, and also that the plastic clays gave only 3–5% sillimanite, whereas the lean clays (kaolins) gave 25% under similar conditions of firing.

In Fig. 3 is shown the results of a thermal analysis of North Carolina kaolin, determined from the time-temperature readings taken on heating a sample of the clay in a resistance furnace. It shows that most of

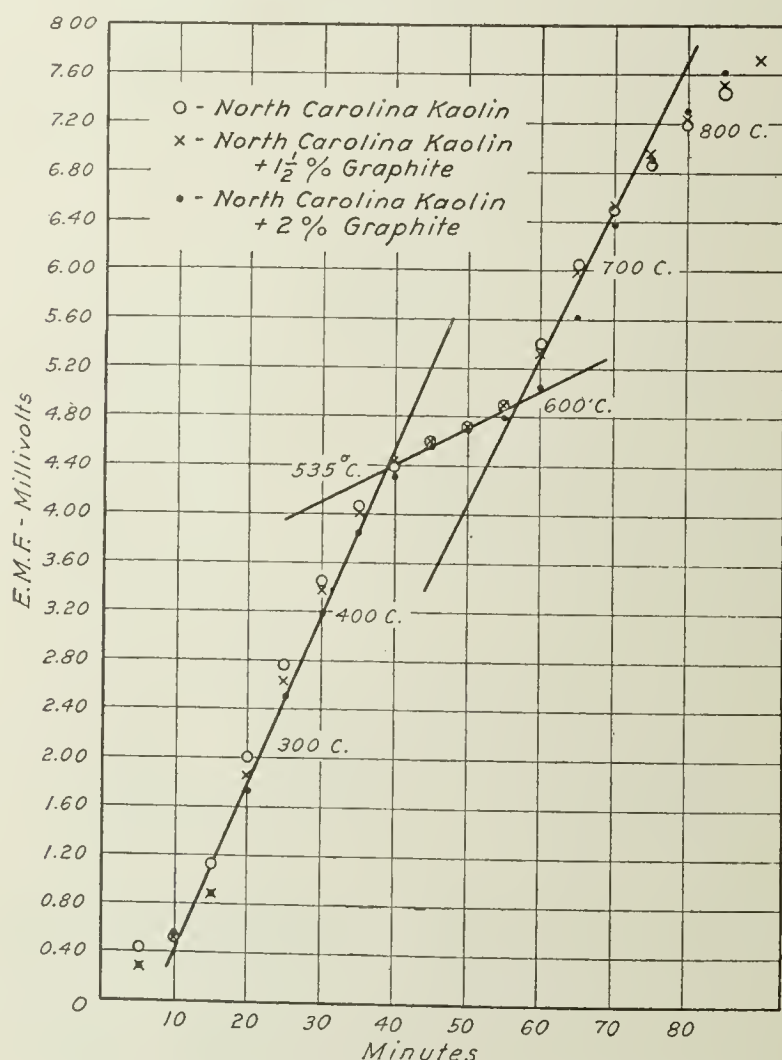


FIG. 3.—Thermal analysis of North Carolina kaolin.

the water of combination is disengaged between 535° and 600°.

Satoh¹ has determined qualitatively, by a very sensitive differential method, using quartz sand as a comparison substance, the heat reactions occurring in a Japanese kaolinite. His results may be summarized as follows

- (1) Heat absorption up to 100°, due to evaporation of moisture contained in the specimen.
- (2) Weak heat evolution from 100° to 300°, possibly due to oxidation of foreign minerals and organic substances.
- (3) Heat absorption from 450° to 650°, due to the dehydration of the kaolinite.
- (4) Heat absorption from 650° to 700°, due to the dissociation of kaolinite into free alumina and free silica.
- (5) Weak heat evolution near 950°, due to the polymerization of the alumina.
- (6) Weak heat evolution between 1200° and 1300°, due to the formation of amorphous sillimanite by the recombination of dissociated free alumina and free silica.

7. Evacuation of Raw Clays.—In preliminary runs the platinum container was filled with the powdered clay, and then evacuated in the system. Under these conditions, even with perfect control of the rate of evacuation, it was uncertain whether the clay had remained in the container, or had been partly expelled by the sudden expansion of gases. It was then found necessary to mold and press the clay, as described elsewhere, in order to keep the clay in the container. This procedure has a number of recommendations apart from the above-mentioned one. It approaches the methods used in practice, and also allows a larger sample to be employed—roughly from 200 to 300 grams.

¹ S. Satoh, *Jour. Amer. Ceram. Soc.*, **4**, 182–94 (1921).

8. **Pressures Developed by the Dissociation of Clays.**—Throughout the experiments, the vacuum pump is kept running, and with unhydrated materials, the pressure is kept down to a fraction of a mm. of mercury throughout the run. With clays, as the temperature varies, and with continuous withdrawal of the water vapor by the pump, a pressure is developed in the calorimeter depending upon the quantities of water vapor being expelled. These are not equilibrium vapor pressures, but they show relatively the velocities with which the dissociation of the clay takes place, as the temperature rises. Figures 4, 5, 6 and 7 show the changes in pressure with temperature for the clays investigated.

In the range 0–400°, the increase in pressure between 30° and 100°, shows that the clays are giving off adsorbed moisture held so tenaciously

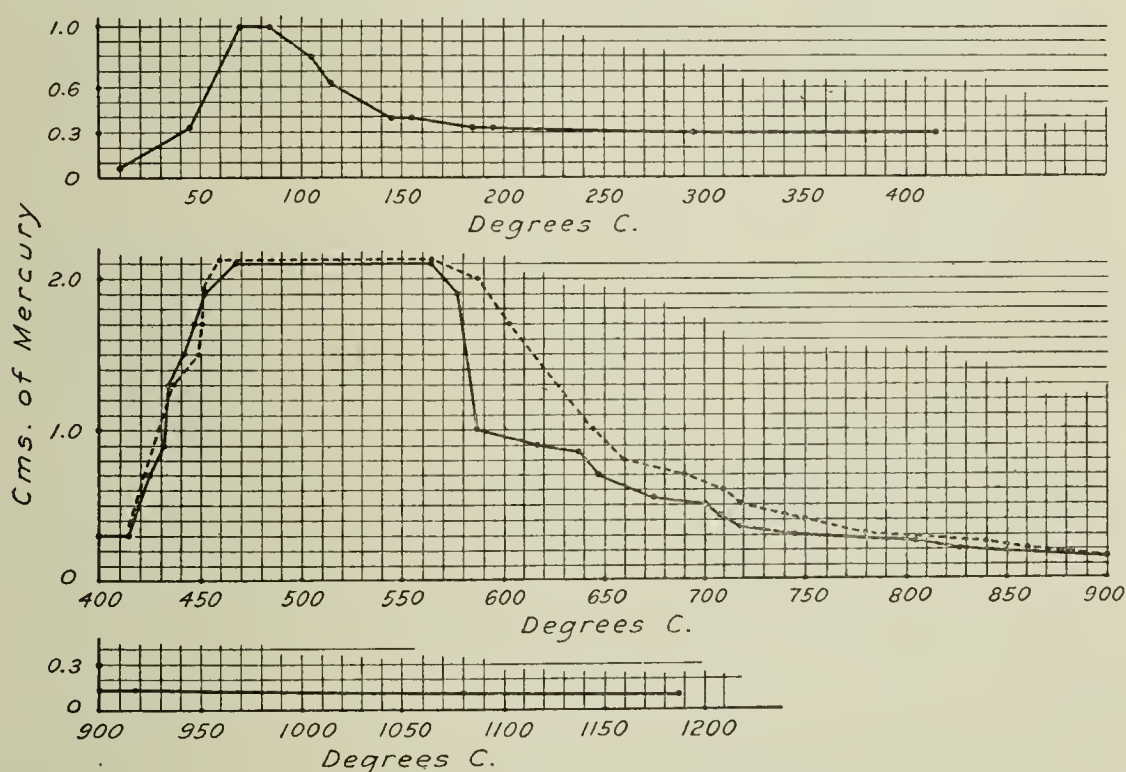


FIG. 4.—Pressure developed by the dissociation of North Carolina kaolin.

as not to be given off by the clays on drying at 110° at atmospheric pressure, or by continued evacuation at room temperatures.

In the range 400–900°, the dehydration of the clays seems to take place in two stages. In the first stage, the evolution of water vapor starts rapidly at about 475°, developing a pressure of about 2.2 centimeters. This maximum is maintained while the temperature rises 100–200°, depending upon the clay. Then appears the second stage, in which the dehydration velocity is suddenly lessened, but falls in a rather decisive and continuous manner, while the temperature rises 200–300° depending upon the clay.

In the range 900–1200°, only those clays containing organic matter developed pressures. The Laclede-Christy raw flint clay showed only a slight increase in pressure, but the Tennessee ball clay No. 5 developed

a rather high pressure. The run on the latter clay through the ranges 400–900°, and 900–1200°, was characterized by extremely bad odors issuing from the vacuum pump, due to the decomposition of the organic matter

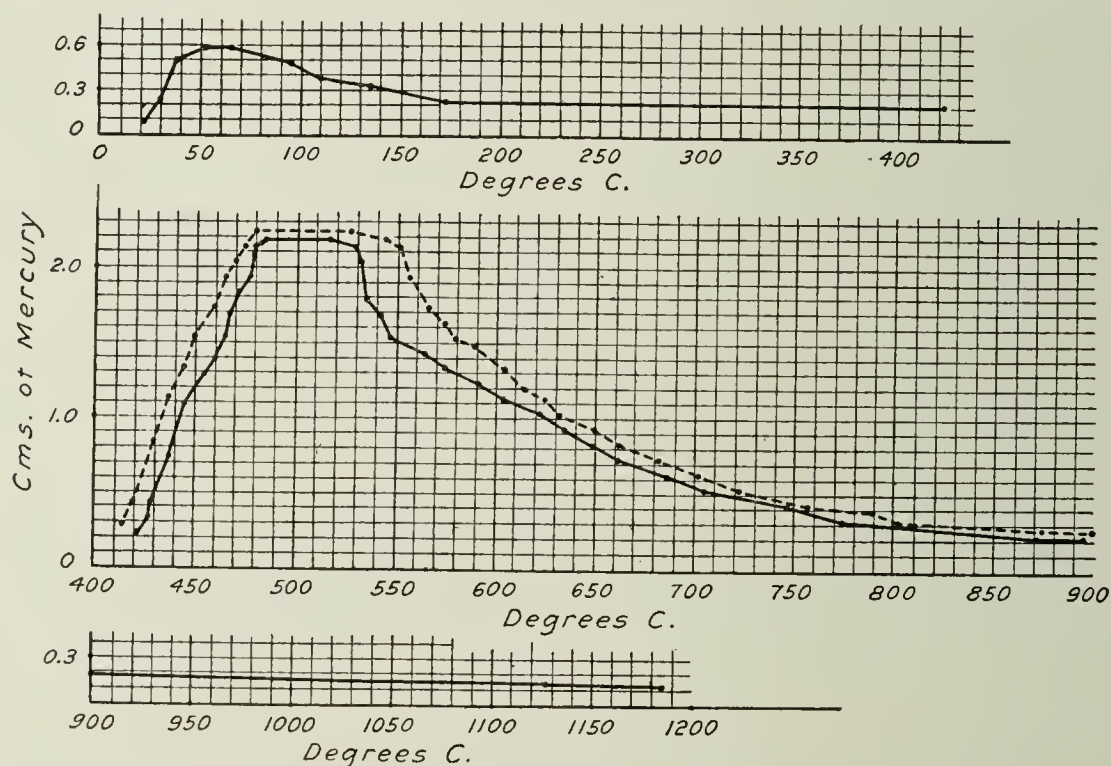


FIG. 5.—Pressure developed by the dissociation of A-I English china clay.

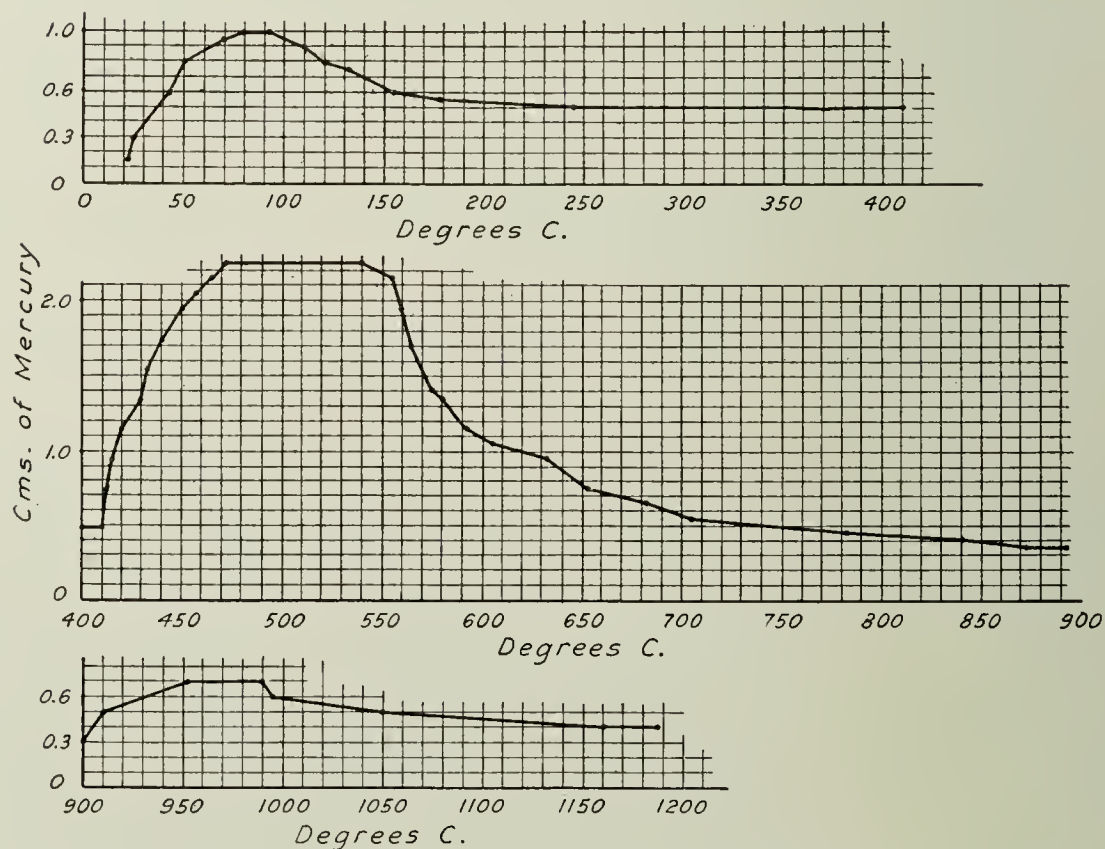


FIG. 6.—Pressure developed by the dissociation of Tennessee ball clay No. 5.

present. After cooling, the clay was found to be colored black throughout.

9. **The Heat Effect of Carbon and Sulphur in Clays.**—The combustion of one gram of carbon to carbon dioxide liberates 8080 calories of heat.

The combustion of one gram of sulphur to sulphur dioxide liberates 2240 calories. If the clay contains an appreciable amount of these constituents, especially of the former, the heat effect is theoretically large.

From the "Paving Brick Clays of Illinois,"¹ the following are the carbon and sulphur contents of some usable clays:—

	K ₁	K ₃	K ₄	K ₅	K ₇	K ₁₄	K ₁₅	F ₁	Average
S in %	0.27	0.16	0.14	0.11	0.13	0.24	0.25	0.32	0.18
C in %	1.44	1.50	.72	1.26	.71	1.01	.90	.92	1.05

Assuming these averages for a clay, the heat given up by the complete combustion of the carbon and sulphur in 100 grams of clay would be:

For C $1.05 \times 8080 = 8484$ calories

For S $0.18 \times 2240 = 403$ calories

—————

8887 calories

Assuming the specific heat of clay to be 0.70 in the range of combustion, 400–900°, then if heat was evolved at one time, and if all of the heat went to raising the temperature of the clay, the sudden rise of temperature would be about 125°. In practice, since the oxidation period extends over a long length of time, and over a wide range of temperature, such sudden increases in temperature are not to be expected. The heat evolved, however, is taken up by the material and its surroundings.

While obtaining the thermal analysis of the North Carolina kaolin an attempt was made to obtain a heat effect with the addition of 1.5% graphite, and in another case with 2% coal. The attempts were unsuccessful because these materials burned only partially, and also because the heat generated went to heating the furnace as well as the clay.

In the vacuum furnace there is no opportunity for the carbon and sulphur to oxidize and burn, hence these heat effects are lost. It is for this reason also that pure clays were selected.

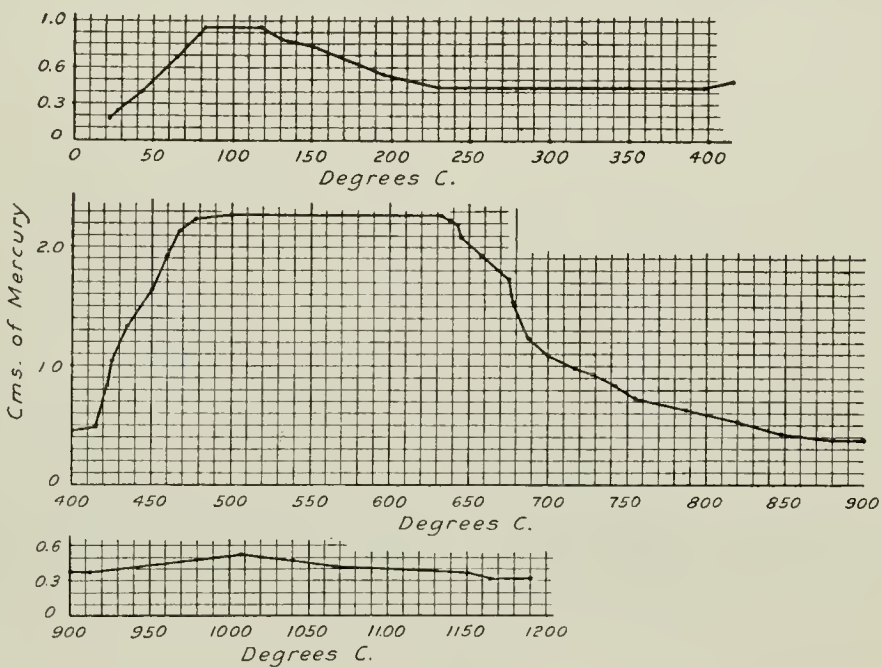


FIG. 7.—Pressure developed by the dissociation of Laclede-Christy raw-flint clay.

¹ Ill. State Geol. Surv., *Bull.* 9, 284–5 (1908).

III. Description of Apparatus

10. **General Set Up.**—The following is a detailed description with dimensions of the apparatus. Fig. 8 is a photograph of the apparatus ready for a run. The letters correspond with those in the figures.

- (a) *Ice Water Tank.* A wooden barrel 32 inches deep and 20 inches in diameter, heavily lagged on bottom and sides with felt.
- (b) *Tube Stirrer.* A rotating metal spiral in a copper cylinder 36 inches long and 5 inches in diameter.
- (c) *Needle Valve.* A $\frac{1}{4}$ -inch brass globe valve, set between the ice

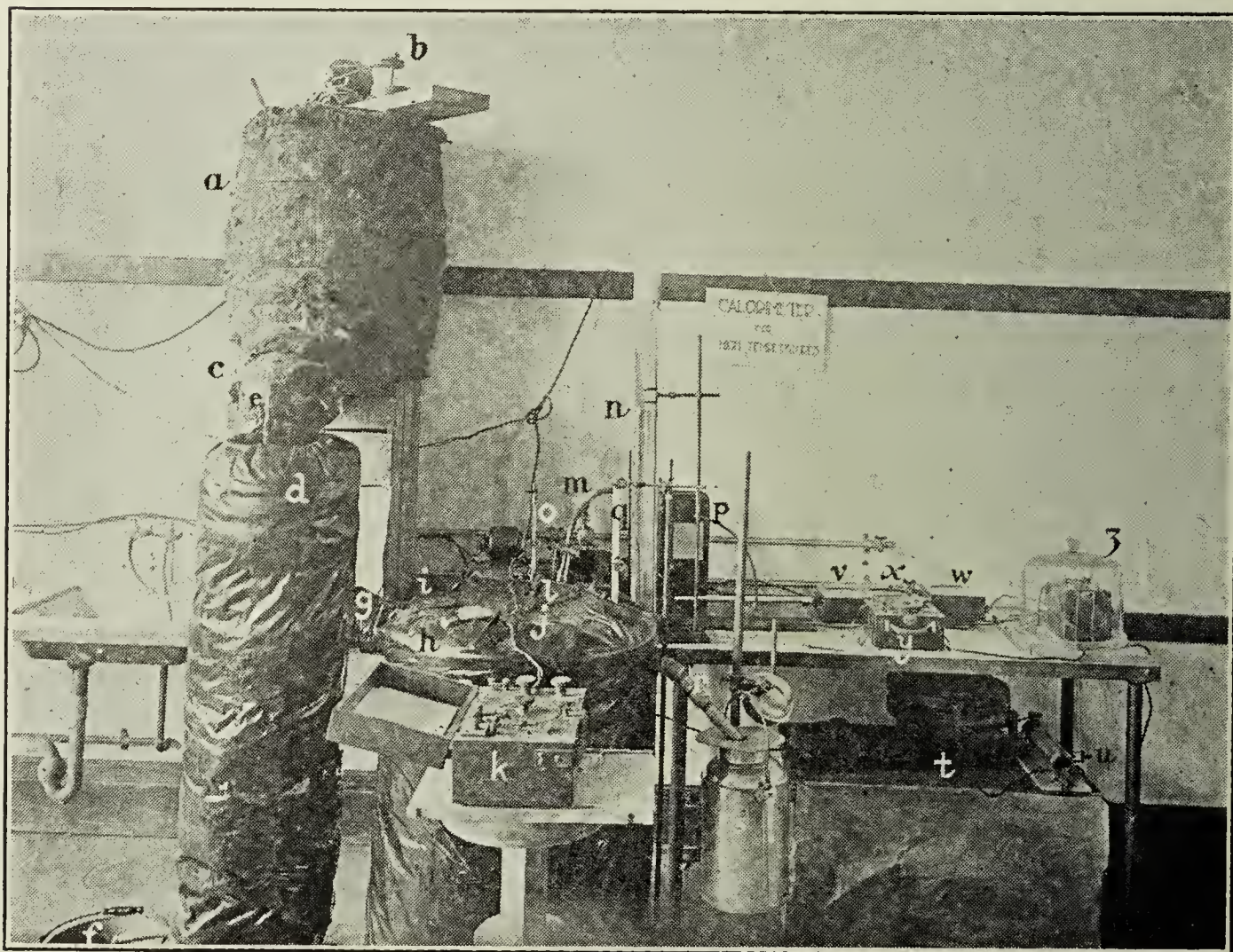


FIG. 8.—General view of apparatus.

water tank and the tube water cooler. With the valve wide open and ice water passing through the coils, the capacity is about 1000 cubic centimeters per minute.

- (d) *Tube Water Cooler.* A galvanized iron cylinder, 48 inches high, 10 inches in diameter, containing the copper coils, with false perforated bottom, and with 1-inch outlet at bottom.

Copper Coils. Two coils, about 50 feet each, and $\frac{3}{8}$ -inch and $\frac{1}{2}$ -inch in diameter, respectively. They are coiled in a close spiral 6 inches in diameter and for a depth of 30 inches. They are con-

nected at the inflow end with a copper box into which the ice water flows from the ice water tank. At the outflow end there is an overflow box, made of copper, 3 inches deep and 3 inches in diameter, with the water level at $1\frac{1}{2}$ inches. The top of overflow box is 10 inches below the top of the galvanized cylinder, and the box has a copper tube extending out of it, to hold the long range zero-degree thermometer.

- (e) *Thermometer, 0°, Long Range.* Mercury bulb, $1\frac{1}{4}$ inches long, mercury thread 16 inches long to 0° mark. Graduated in $\frac{1}{10}^\circ$ divisions from 0° to 10°. Stem $\frac{1}{4}$ -inch in diameter. Immersed in water in box to depth of $1\frac{1}{2}$ inches. It was compared with a standard in ice water, and found to be exact at 0°.
- (f) *Drainage Outlet.* The outlet for drippings from the ice water in the tube water cooler.
- (g) *Vacuum Tube.* A tube 12 inches long and $\frac{1}{2}$ -inch inside diameter was sealed at the ends onto a tube of $\frac{3}{4}$ -inch inside diameter, leaving an air space between them. This space was evacuated to .002 millimeters pressure of mercury, and sealed off. The tube connects the overflow box, through the wall of the galvanized cylinder, to the calorimeter bath, through a hole in its side. The tube is heavily lagged with felt and covered with oilcloth.
- (h) *Calorimeter Bath.* An enameled iron bath, 33 inches high and 22 inches in diameter. It is $29\frac{1}{2}$ inches deep from the overflow. With the calorimeter in place, the bath will hold 400 pounds of water, at 17°. It is lagged with 2-inch felt on sides and bottom, and stands on a wooden platform 5 inches above the floor. The felt is covered with oilcloth to prevent it from getting wet.
Bath Cover. This is a galvanized iron cover that fits tightly, and is covered with a 2-inch layer of felt. Soldered metal tubes in the cover allow for the extension of the stirrer shaft, Beckmann thermometer, electric current leads and vacuum connection.
- (i) *Tube-Stirrer.* A rotating metal spiral in a copper cylinder 28 inches long and 3 inches in diameter. The stirrer is fastened to the side of the bath, and rotates so as to draw the water downwards in the tube.
- (j) *Electric Current Leads.* Three pairs of wires emerge from a central tube in the cover. (1) Heavy wires for the current, (2) light wires for the potential leads, and (3) light wires for the thermocouple leads.
- (k) *Potentiometer.* A Leeds and Northrup instrument with millivolt scale graduated in $\frac{1}{10}$ millivolts. The one hundredths can easily be estimated. The two graphs seen next to the instrument are (1) the e. m. f. temperature conversion chart, and (2) the deviation curve for the thermocouple.

- (l) *Vacuum Connection.* A rubber hose connection from the calorimeter in the bath, through a tube in the cover, and connected on the outside of the bath to a glass double *L*. The double *L* then connects to (1) Vacuum pump, (2) mercury *U*-manometer and (3) stopcock leading directly to the atmosphere.
- (m) *Vacuum Pump.* A Hyvac pump made by the Central Scientific Company. The pump is kept running continuously throughout an experiment.
- (n) *Mercury U-Manometer.* The long arm was evacuated and sealed off. When attached to the evacuated apparatus, the mercury in both arms is at the same level.
- (o) *Stopcock and Pinchcock.* A well ground stopcock with a pinchcock on a heavy rubber hose, to control the pressure in the vacuum furnace when necessary.
- (p) *McLeod Gauge.* Capable of reading to one thousandth of a millimeter of mercury. The gauge is connected to the vacuum pump through one arm of a *T*, the other arm being connected to the double *L*.
- (q) *Beckmann Thermometer.* Graduated in one hundredths of a degree. The bulb $1\frac{1}{8}$ inches long and $\frac{1}{2}$ -inch in diameter rests in the water in the bath, a few inches away from the overflow.
- (r) *Overflow (Bath).* As ice water is put into the bath through (g), the overflow of the bath escapes through (r).
- (s) *Tared Container.* Cans with close fitting covers are used to collect the bath overflow.
- (t) *Rheostats.* Two plate rheostats in series. A slide wire rheostat in parallel with one plate rheostat for fine adjustment.
- (u) *Knife Switch.*
- (v) *Ammeter.* 0–10 ampere range. Divisions, 0, 1, 2, from 2–10 in one-tenths.
- (w) *Ammeter.* 0–50 ampere range. Divisions, 0, 5, 10, from 10–50 in $\frac{1}{2}$ units.
- (x) *Knife Switch.*
- (y) *Wattmeter.* General Electric Company. Scale 0–500 watts. Amperes 10 and 20, volts 75 and 150, maximum combinations.
- (z) *Test Meter.* Portable Type IB-5, for alternating current circuits. Amperes 1 and 10. Volts 110. Cycles 60. Two coils, for 1 ampere fuse and for 10 ampere maximum through instrument. The instrument is a revolution counter with three dials.
Dial (1) reading total of 100 revolutions, divided in 10's.
Dial (2) reading total of 10 revolutions, divided in units.
Dial (3) reading total of 1 revolution, divided in $\frac{1}{100}$ revolution.
When using the 10 ampere coil on the 110 volt circuit, but irrespective of the voltage drop on it, the constant for the instrument

is 0.6 watthours per revolution. Maximum load, 10 amperes. General Electric Company product.

11. **Calorimeter Set Up.** (Description of Figure 9.)—(a) *Platinum Container*. Made of 0.004 inch sheet, $8\frac{1}{4}$ inches high, $1\frac{3}{8}$ inches in diameter, with the bottom end closed, weighing 51.0 grams.
- (b) *Alundum Furnace Core*. 10 inches long, $1\frac{1}{2}$ inches bore, $\frac{1}{8}$ -inch wall, closed at one end. It has a double thread for holding the resistance wire in place— $\frac{1}{6}$ -inch apart.
- (c) *Alundum Cylinder*. 10 inches long, $1\frac{3}{4}$ inches bore, and $\frac{1}{8}$ -inch wall, open at both ends.
- (d) *Porcelain Cylinder*. Made of a good refractory body, 11 inches high, 3 inch bore, and closed at one end.
- (e) *Nickel Cylinder*. Made of sheet nickel, one millimeter thick, with a nickel sheet cap at the bottom. It is just large enough to hold the porcelain cylinder.
- (f) *Porcelain Upper Support*. This is made to fit over the top of the nickel cylinder, $3\frac{1}{4}$ inches to $3\frac{1}{2}$ inches in diameter, ending in a hollow stem, $1\frac{1}{8}$ inches outside diameter and $1\frac{1}{4}$ inches high, which fits into the calorimeter cover.
- (g) *Porcelain Lower Support*. This is made to hold up the nickel cylinder in a holder $3\frac{1}{2}$ inches in diameter, and 1 inch high, the holder terminating in a slightly tapered hollow stem 3 inches long and tapered from 1 inch to $\frac{3}{4}$ -inch.
- (h) *Porcelain Insulator*. About 6 inches long, 6 millimeter bore and 2 millimeter wall, closed at one end. It is imbedded in the material held in the platinum container, so that the closed end is situated half way down the material and centrally located.
- (i) *Porcelain Insulator*. 6 millimeter bore and 2 millimeter wall.
- (j) *Platinum Resistance Wire*. 28 feet long, 0.036 inch in diameter and weighing 120.30 grams, wound non-inductively on the core (b). Above the core, the ends of the wire are trebled so as to form heavy leads for the current, and are encased in the porcelain insulators.

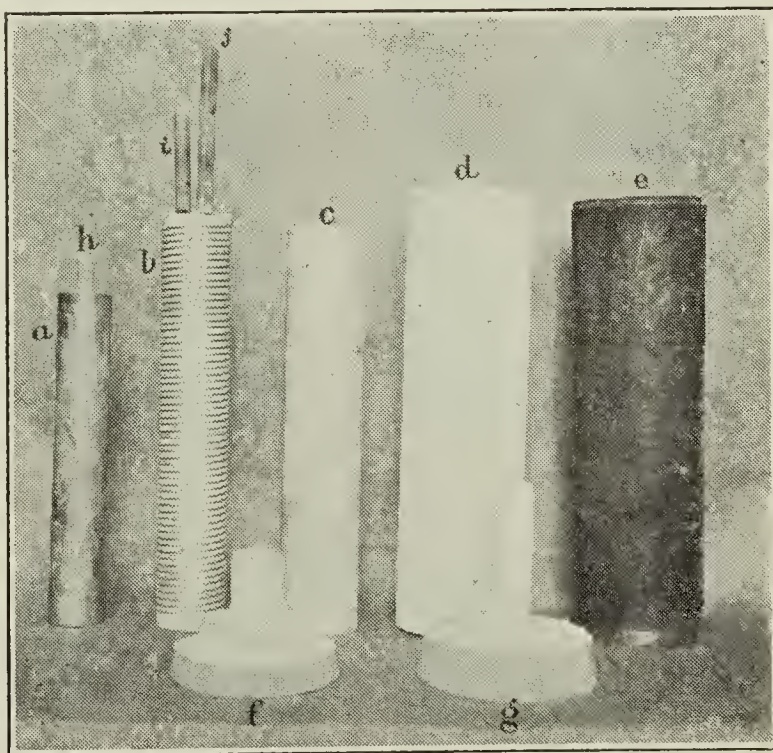


FIG. 9.—Platinum container and furnace parts.

- Description of Figure 10.**—(a) *Metal Calorimeter*. Made of nickel-plated copper, $14\frac{3}{4}$ inches high, $7\frac{3}{4}$ inches inside diameter, and $\frac{1}{8}$ -inch wall. It has a bottom screwed in and soldered air tight. In the center of the bottom is soldered a hollow metal inset which holds the tapered end of the porcelain lower support in place.
- (b) *Calorimeter Cover*. Made of nickel-plated iron. It slips onto (a) snugly to a depth of $\frac{3}{4}$ inch. Its center is cut out and threaded to take a $1\frac{3}{8}$ inch pipe.
- (c) *Heavy Copper Leads*. These are connected to the platinum leads by means of nickel screw connectors.

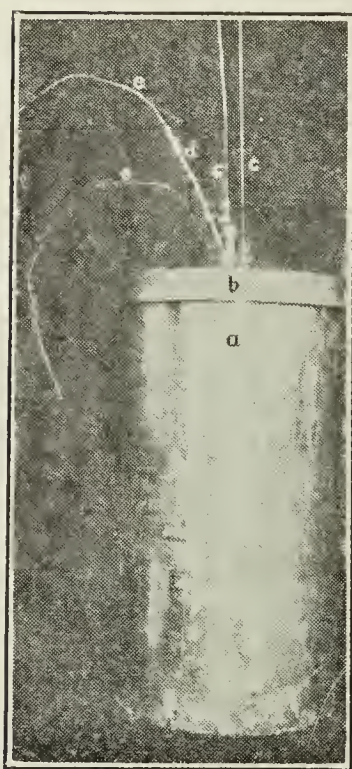


FIG. 10.—Metal calorimeter with furnace and thermocouple lead wires.

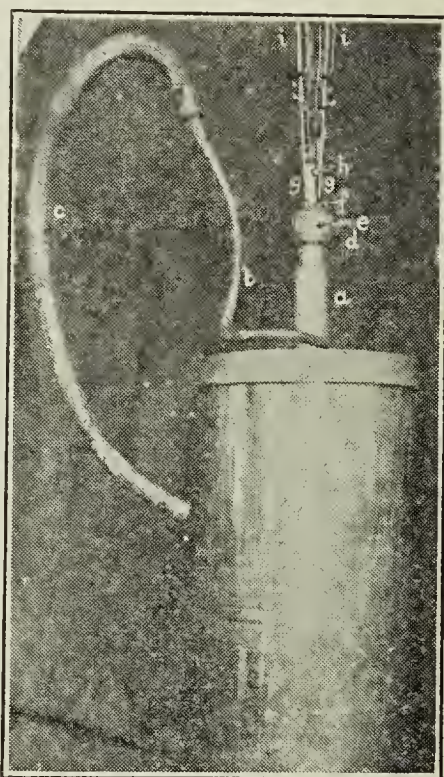


FIG. 11.—Metal calorimeter with cover stem showing excavating tube and partially insulated lead wires.

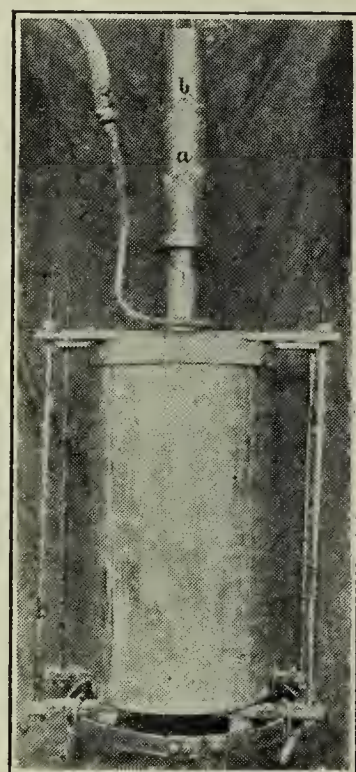


FIG. 12.—Calorimeter ready to be immersed in water bath.

- (d) *Porcelain Insulators*. One millimeter bore and one millimeter wall.
- (e) *Thermocouple*. Platinum, platinum-rhodium thermocouple, two feet long.

- Description of Figure 11.**—(a) *Cover Stem*. Made of nickel-plated copper, threads into calorimeter cover. It is $4\frac{1}{4}$ inches long and has a bore of $1\frac{1}{8}$ inches.
- (b) *Copper Evacuating Tube*. Made of $\frac{5}{16}$ -inch stock, and soldered into the cover stem about $\frac{1}{4}$ -inch above the calorimeter cover.
- (c) *Rubber Pressure Hose*. It connects the calorimeter to the vacuum pump, by way of the copper evacuating tube. It is coated with beeswax to make it air tight.

- (d) *Threaded Collar*. Two inches in diameter, sweated onto the upper end of the cover stem.
- (e) *Rubber Stopper*. This fits into top of cover stem.
- (f) *Glass Tube Insulators*. These extend about 2 inches above the top of, and $\frac{1}{2}$ -inch below the bottom of, the rubber stopper, and allow the heavy copper leads to pass through, and keep them apart for insulation purposes.
- (g) *Heavy Copper Leads*. The same as shown in Fig. 10.
- (h) *Porcelain Insulator*. Six millimeter bore and 2 millimeter wall. It passes through the rubber stopper and harbors the thermocouple, insulating it from the current lead wires. One wire of the thermocouple is strung with small bore porcelain insulators to insulate the two thermocouple wires from each other.
- (i) *Current and Potential Leads*. To each heavy copper lead is attached, by means of a copper screw connector, two copper insulated leads, a heavy wire for the current, and a light wire, known as the potential lead wire, to be connected to the test meter.

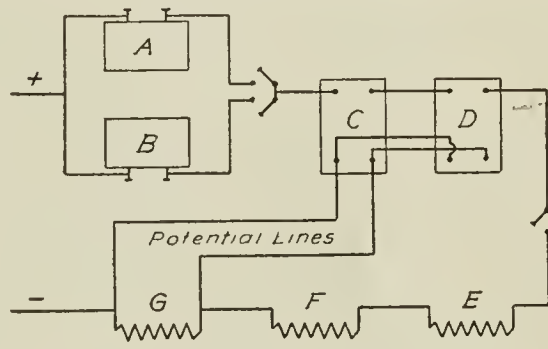


FIG. 13.—Electric wiring set up.

Description of Figure 12.—(a) *Copper Extention Tube*. Copper Tube, $9\frac{1}{4}$ inches high and 2 inches in diameter that threads onto the collar of the cover stem. It is merely a protection for the wires from the surrounding water.

(b) *Water Level*. The water in the calorimeter bath reaches to level (b).

12. Electric Wiring Set Up. (Figure 13 Illustrates the Set Up.)—

(A) *Ammeter*. 0–10 ampere range.

(B) *Ammeter*. 0–50 ampere range.

(C) *Test Meter*. Revolution counter. Alternating current only.

(D) *Wattmeter*. Indicating wattmeter.

(E) *Rheostat*.

(F) *Rheostat*.

(G) *Electric Furnace*. Platinum wound furnace, operated on 110 volt alternating current circuit.

IV. Experimental Data Necessary for Calculating Specific Heats

In any range of temperature for which a run is made, the following data must be known:—

- (1) The electrical energy expended in the resistance furnace.
- (2) The heat absorption of the ice water used to counteract the rise in temperature of the bath.

- (3) The temperature of the inflowing ice water.
- (4) The temperature of the bath.
- (5) The temperature of the material under investigation in the resistance furnace.

The following paragraphs describe the instruments used to obtain the above readings, and give their sensitivity and calibration, and all data and factors necessary for converting their readings to the purpose at hand.

13. Electrical Energy.—(a) *Portable Test Meter.* This instrument, of the induction coil type, is essentially a calibrated revolution counter. For the 10 ampere coil used in this work, the rating is 0.600 watthour per revolution, or 2160 watts per revolution. Allowing 4.186 watts to the calorie, gives the meter a value of 516.0 calories per revolution. The instrument was calibrated over its full range at 110 volts and found to be correct to better than 0.1%. At lower voltages and at the lowest wattages used in the experimental work, a comparison with an electrodynamicometer type of wattmeter gave concordant results to within the accuracy of the comparison instrument of 0.1%.

(b) *Indicating Wattmeter.* It was found expedient to have an ordinary indicating wattmeter in the line, so that the wattage through the furnace could be seen at a glance, and easily controlled by means of the resistance in series with the furnace. A small amount of current is used in actuating the wattmeter, but as it is used in all runs for approximately the same wattages and for the same lengths of time, this correction is taken care of automatically.

14. Ice Water Heat Absorption.—(a) *Weighing the Overflow.* The run is started with the bath full and continuously stirred, and with the temperature of the bath constant. Ice water is allowed to flow in to keep the temperature of the bath constant, as heat is being transferred to the water from the calorimeter. The overflow is collected in cans, and for any range of temperature, the weight collected is equal to the weight of ice water delivered to the bath. The overflow is weighed to a gram.

Knowing the temperature of the ice water going into the bath, and the temperature of the overflow, the heat absorbed in this change in temperature is known. The total heat absorption of the ice water for the range of temperature can then be calculated.

Some of the ice water is utilized in counteracting the rise in temperature of the bath due to the heat caused by the friction of the stirrer in the bath.

(b) *Ice Water Correction for Stirring Friction.* After runs had been made on two days several months apart, the bath was allowed to be stirred for periods of four hours and the rise in temperature due to stirring noted. The increase in temperature amounted to 0.052° per hour.

On other occasions, the amounts of ice water necessary to lower the temperature of the bath 1°, were determined. In one case, 8442 grams

of ice water cooled the bath from 22.940° to 21.910° , with constant stirring for 30 minutes. As the raising of the temperature of the bath due to stirring is 0.026° , the true lowering of temperature of the bath is $22.940^{\circ} + 0.026^{\circ} - 21.910^{\circ} = 1.056^{\circ}$. Hence at the average temperature of 22.425° , it requires 7994 grams of ice water to cool down the bath 1° . To counteract one hour of stirring at 22.425° requires $7994 \times 0.052 = 416$ grams of ice water.

At the average temperature of 27.587° it requires 6554 grams of ice water to cool down the bath 1° . At 27.587° , one hour of stirring will be counteracted by 341 grams of ice water. The ice water used in all experiments had a temperature of 0° .

By plotting these results the ice water stirring correction for any temperature of the bath can be found by inspection.

(c) *Heat Capacity of Water.* By means of an electrical continuous flow method, Callendar¹ and Barnes² have found the specific heat of water over the range of 0° to 100° . Callendar gives the variation of total heat h , with the temperature t , in the form of an equation that is of great value in the present work, for it is necessary to know the heat capacity of the ice water used to keep the temperature of the bath constant.

$$h - t = 1.1605 \log_{10} \left(\frac{t + 20}{20} \right) - 1.1464 \left(\frac{t}{100} \right) + 0.42 \left(\frac{t}{100} \right)^2 + 0.30 \left(\frac{t}{100} \right)^3$$

Thus the heat absorbed by one gram of ice water in changing its temperature from 0° to 23.560° amounts to 23.709 calories.

(d) *Heat Capacity of the Bath and Contents.* From preliminary experiments it was determined to be 180,440 calories.

15. Temperature of the Ice Water.—A long range mercury thermometer has its bulb in the overflow box of the tube water cooler. It measures the temperature of the ice water flowing into the calorimeter bath. The thermometer was compared with a French Standard, certified by the Bureau of Standards, and was found to be correct at 0° . There is no difficulty in having a continuous supply of ice water at 0° , with the arrangement used, provided constant attention is given to it.

16. Temperature of the Bath.—The temperature of the bath is read by means of a Beckmann thermometer graduated in hundredths of a degree, and calibrated against a thermometer recently certified by the Bureau of Standards. The bulb is situated near the overflow and measures its temperature. The temperature of the room is regulated so as to coincide with the temperature of the bath to within a few tenths of a degree.

¹ H. L. Callendar, *Proc. Roy. Soc. (London)*, **86A**, 254-7 (1912).

² H. T. Barnes, *Trans. Roy. Soc. (London)*, **199A**, 149-263 (1902).

17. **Temperature of the Material in the Furnace.**—The junction of a two-foot platinum, platinum-rhodium thermocouple is imbedded in the center of the material which is being heated in the furnace. The two ends of the couple extend one inch above the top of the cover of the calorimeter bath. They are connected to a Leeds and Northrup potentiometer by copper leads. A thermometer hanging just above the bath measures the cold junction temperature, which is corrected in the temperature measurements. The thermocouple and potentiometer were calibrated against the freezing points of pure metals supplied by the Bureau of Standards for such work, and the deviations in temperature were plotted as suggested by Adams.¹

V. Heat Insulation

18. **Furnace Insulation.**—From preliminary work, it was found that the heat loss from the furnace had to be reduced as far as possible. The advantage in decreasing the input of electrical energy was in increasing the fraction of heat expended on the material. This was accomplished

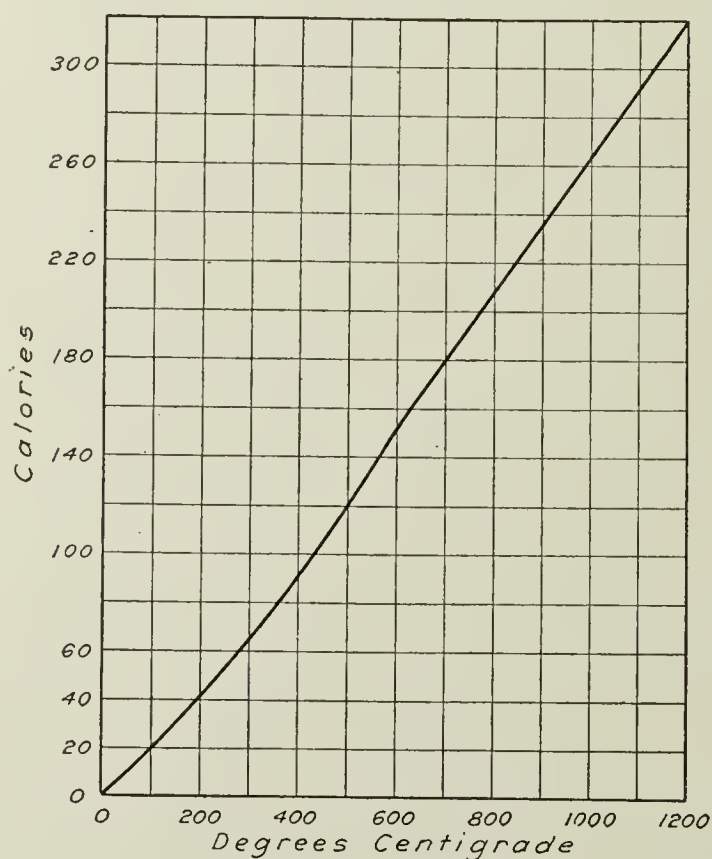


FIG. 14.—Heat capacity of 1 gram of quartz calculated from White's results.

(a) by running the furnace under vacuum conditions instead of at atmospheric conditions, and (b) by packing the furnace core with a good insulating material. In order to reach 1100° under atmospheric conditions, about 750 watts from a 12–15 ampere current had to be expended, whereas with the present vacuum furnace, 350 watts from an 8-ampere current will give 1200° . The maximum current capacity of the test meter is 10 amperes.

It has been found that fused zirconia has the lowest specific heat ($0-100^{\circ}$, 0.1075)² and heat conductivity (about 0.00039)³ of any material suitable for furnace packing.

19. **Bath Insulation.**—The calorimeter bath is covered on its sides, top and bottom with two-inch felt to minimize heat exchange with the room. The temperature of the room was kept to within a few tenths of a degree of the temperature of the

¹ Leason H. Adams, "Symposium on Pyrometry," *Am. Inst. Mining Met. Eng.*, 165–78 (1920).

² J. W. Marden and M. N. Rich, *Bur. Mines, Bull.* **186**, 20 (1921).

³ R. S. Hutton and J. R. Beard, *Proc. Faraday Soc.*, **1**, 266 (1905).

bath so as to minimize the radiation exchange. The felt is covered with oilcloth to prevent it from getting wet.

20. **Insulation for the Ice Water System.**—The ice water tank and the tube water cooler are covered on all sides with two-inch felt.

The valve and pipe connections between the ice water tank and the tube water cooler are very heavily covered with felt. The connection between the tube water cooler and the bath is a vacuum tube, which is also well covered with felt and oilcloth. The vacuum tube, set at an angle of 30° , is connected by rubber hose to the overflow box in the tube water cooler, and leads the ice water directly into the tube stirrer in the bath by means of another piece of rubber hose.

VI. Preparation for an Experiment

All of the parts of the apparatus mentioned in this chapter are described in Chapter II, and are illustrated in the figures accompanying it.

21. **Preparation of the Sample.**—If the material is inert like quartz, the crushed particles are filled into the platinum container. If the material is a clay, which is finely divided and contains water of combination, it must first be molded.

The clay is made to pass a 20-mesh screen, and then worked with water until a plastic mass is obtained. The mass is then put into a screw press and forced through a $1\frac{1}{2}$ -inch orifice. The stiff column is cut up into pieces 1 to 2 inches long. Half of these pieces are then centrally bored with a $\frac{5}{16}$ -inch cork borer. All of the pieces are allowed to dry at 110° over night. The solid pieces with a total length of 4 inches are trimmed down to fit the platinum container snugly. The hollow pieces are trimmed down to fit the container, and are also hollowed out to allow the porcelain thermocouple protection tube to slide through them. The container is then filled up with these hollow sections, and the protection tube is slipped into place.

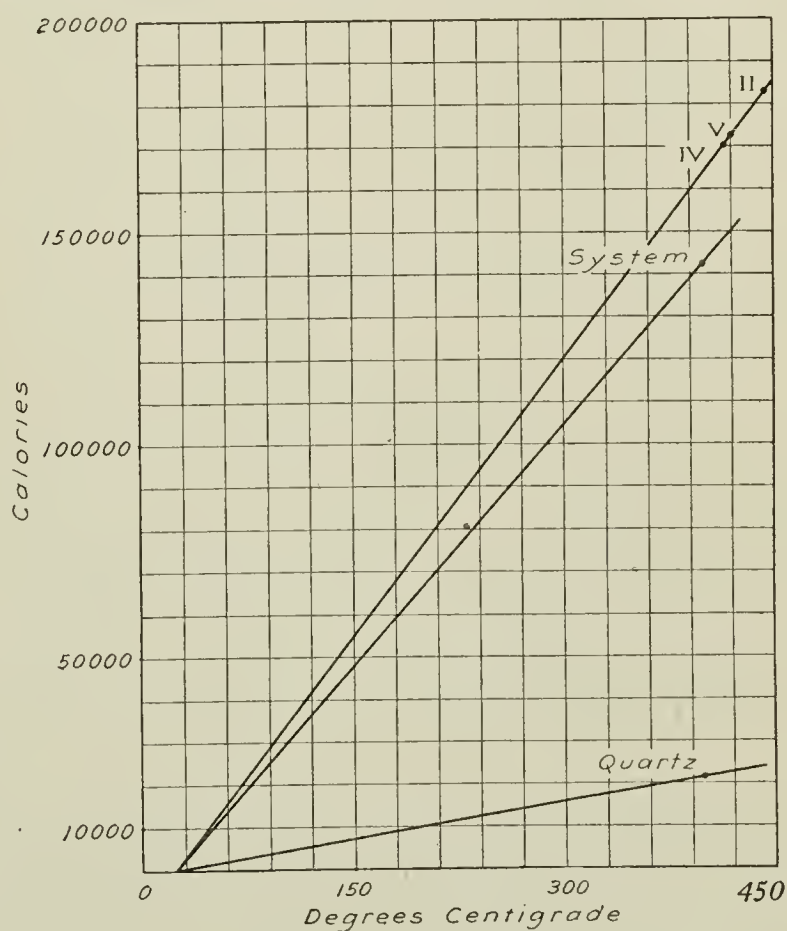


FIG. 15.—Quartz runs and heat capacity of system in range 23.560 – 420°C . Heat capacity of system 23.560 – $400^\circ = 142,400$ calories.

22. **Assembling the Calorimeter.**—The platinum container and its charge are then slipped into the furnace core, so that it stands on the false bottom consisting of a thin alundum disc resting on a porcelain ring. The furnace core is slipped into the alundum cylinder, which is surrounded by the zirconia packing, held in place by the porcelain cylinder, with the nickel cylinder on the outside. The weight of the furnace parts are:—

	Grams
Nickel and porcelain cylinders.....	1406.0
Zirconia packing.....	1321.0
Alundum cylinder.....	220.8
Alundum core.....	205.3
Platinum container.....	51.0

The nickel cylinder and contents are now ready to be set onto the porcelain bottom support which is in its holder in the base of the metal calorimeter.

The porcelain upper support is now put on, and then the metal cover of the calorimeter is forced on.

The lead ends of the platinum resistance wire are now sheathed with the porcelain protection tubes, and are attached by nickel screw connectors to two bare heavy copper leads. The cover stem, provided with a roll of dehydrated mica that fits snugly on the inside, is then slipped over the copper lead wires and screwed into place, thereby holding the porcelain upper support in position by its extension below the cover.

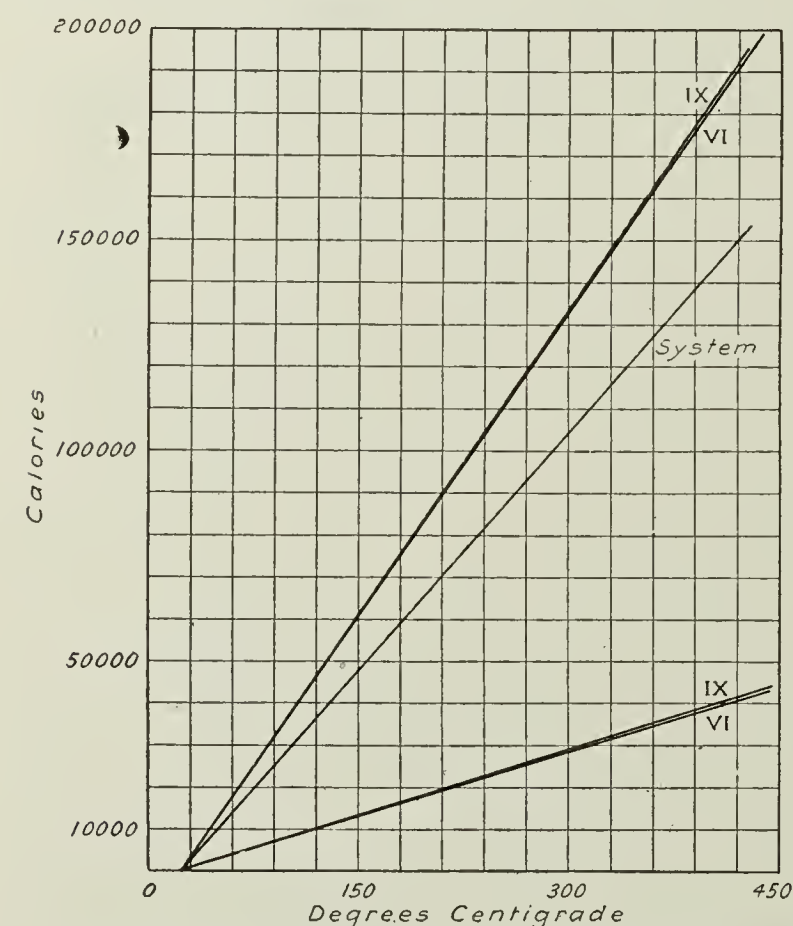


FIG. 16.—Heat capacity of A-I English china clay 247.5 grams in range 24–420°C. VI, 23.560–422° = 41,400 calories; IX, 23.560–415° = 41,000 calories.

A rubber stopper fitting into the cover stem carries in it two short glass tubes through which the heavy copper leads can just pass, and also carries a porcelain protection tube through which the thermocouple wires are led. When the rubber stopper is in place, its porcelain protection tube just touches the porcelain tube that is inserted in the material. The thermocouple is now inserted into place, its two wires being insulated from each other by small porcelain insulators. The copper lead wires are strung with glass tubing and are held in position so that there can be no short circuiting.

The two openings through which the lead wires enter the glass tubes in the stopper, and the openings whereby the thermocouple wires enter the porcelain protection tube, are now sealed with De Khotinsky cement. All other joints are made vacuum tight by painting them with a heavy layer of beeswax. To each heavy copper lead are attached by means of a copper screw connector, the two lengths of insulated copper wire. The screw connectors are insulated with rubber tape. The copper extension tube is now slipped over the four insulated lead wires and over the separately insulated thermocouple wires, and threaded into place. The joint is made water tight with a layer of beeswax. The apparatus is clamped into its metal frame and is ready for immersion in the bath.

23. Evacuating the Calorimeter.—The calorimeter bath is filled with water and the calorimeter set in the middle of it. The cover is put on so that the six wires from the calorimeter pass directly through the central tube. The rubber hose attached to the calorimeter is connected to the vacuum pump. The lead wires are connected to the source of

current and the instruments, and the thermocouple wires are connected to the potentiometer.

The vacuum pump is started and the system is evacuated for several hours, to get rid of adsorbed air. The pressure is then usually below a millimeter. The pump is then shut off, and the system allowed to remain evacuated.

24. Ice Water Supply.—On the day before a run is to be made, the ice water tank is filled with water and crushed ice and stirred continuously. The tube water cooler is filled with crushed ice. From time to time the ice is shaken down and packed around the coil to insure intimate contact.

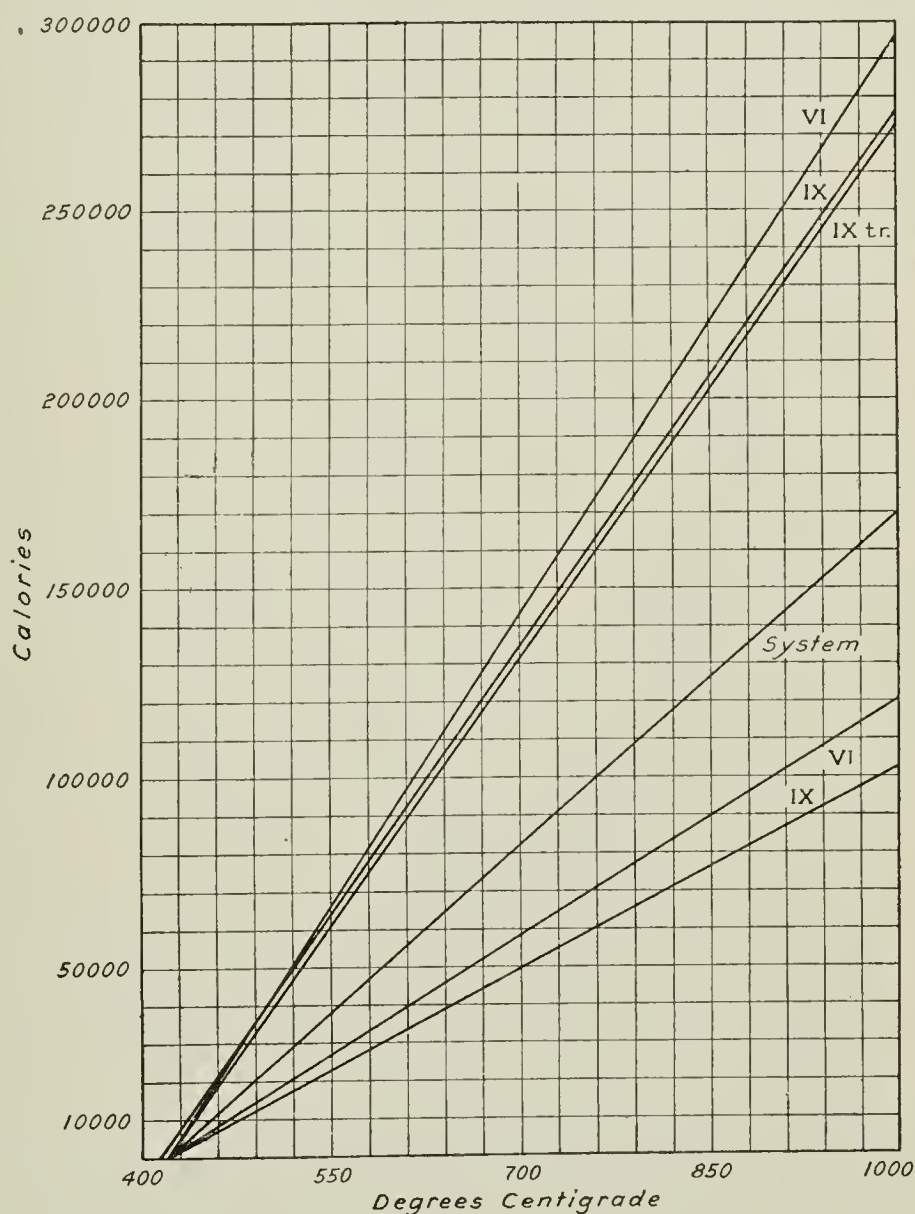


FIG. 17.—Heat capacity of A-I English china clay 247.5 grams range 400–900°. VI, 421–900° = 121,200 calories; IX, 421–900° = 103,200 calories.

This process of packing and refilling is made every half hour during the run. The thermometer in the overflow box records the temperature of the ice water. During the run, the ice water tank is frequently supplied with water and ice, to keep the head of water on the valve constant. Usually about 600 lbs. of ice are sufficient for the complete run.

VII. Experimental Procedure

25. **Ascending Temperatures.**—When the calorimeter bath is stirred and filled just to overflowing, and the temperatures of the bath and room are the same, with the ice water supply at 0° , and the vacuum pump working smoothly, the test meter is read and a tarred can placed under the overflow. The current is turned on, and the resistance in the circuit varied to give the required wattage through the furnace. The wattage is con-

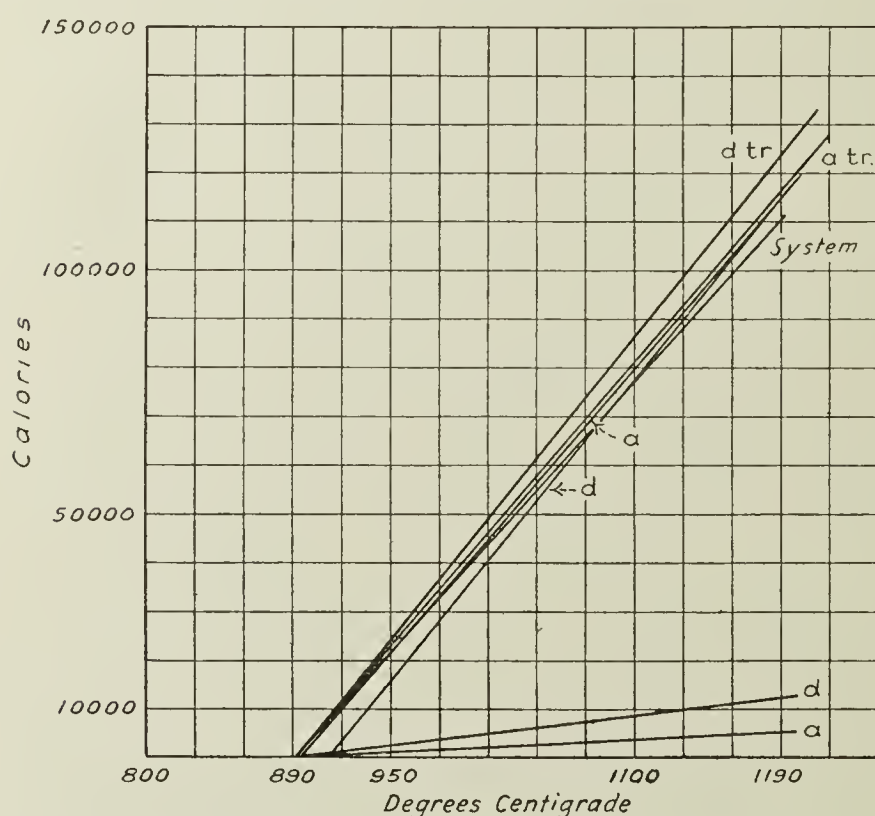


FIG. 18.—Heat capacity of A-I English china clay 216.2 grams in range $900\text{--}1200^{\circ}\text{C}$. IX, Ascending temp. (a) $892\text{--}1187^{\circ} = 5,200$ calories. Descending temp. (d) $1187\text{--}892^{\circ} = 12,200$ calories.

tinuously watched and kept constant, for from preliminary work it is known that this wattage will raise the furnace temperature the required amount.

The temperature of the bath is kept constant by varying the ice water flow into the bath. Normally the fluctuation of the temperature can be controlled to $\pm 0.01^{\circ}$. The test meter readings are recorded. If the material being heated is a clay, the pressure developed in the furnace is recorded with the corresponding temperature of the clay. If the substance

being heated is an inert material like quartz, a pressure in the calorimeter is artificially developed by working the pinchcock attached to the stopcock tube in one arm of the double L-tube in the vacuum system. The pressure curve followed is that of the clays at corresponding temperatures, thus making the heat insulation for the quartz run equivalent to the heat insulations found for the clay runs.

When equilibrium has been attained, that is when the furnace temperature has reached its maximum, the exchange of heat between the calorimeter and the ice water inflow is balanced. In practice, the equilibrium is considered to have been attained, when the rise in temperature of the

furnace, in the neighborhood of the maximum temperature, is even and very slow, in the order of $1\frac{1}{2}^{\circ}$ a minute. When this stage has been reached, the furnace temperature and test meter readings are recorded, and the overflow can replaced by an empty one, as soon as the temperature of the bath coincides with the initial temperature of the run. The wattage is then increased and the procedure repeated for the second range of the run.

The data obtained are then the total electrical energy consumed in the furnace, the total weight of ice water used, and the temperature to which the material has been heated. The weight of the material, the temperature of the ice water and of the bath, are already known. Similar data are found for each stage of the run.

With clays the main dehydration period exists between 420° and 900° , making it necessary to have this range all in one stage of the experiment. This then limits the run to three stages for the ascending temperatures. With 90–110 watts 420° can be reached in the furnace; then increasing to 200–240 watts will raise the temperature to 900° , and finally increasing to 300–350 watts, will give 1200° as the maximum temperature.

26. Descending Temperatures.—At the end of the last ascending temperature range, when equilibrium has been reached, the current is cut off, and the heat given up by the calorimeter to the bath is balanced by ice water. The temperature falls fast and continuously.

The descending run is divided into two stages, roughly 1200 – 900° , and 900 – 700° , the only data being obtained, are the quantities of ice water used for each descending range of temperature.

VIII. Heat Capacity of the "System"

27. Heat Capacity of Quartz.—The quartz used in the calibration runs was a Baker and Adamson product of crushed crystals, analyzing 99.98% SiO_2 , and having indices of refraction 1.544–1.553, and a specific gravity of 2.654.

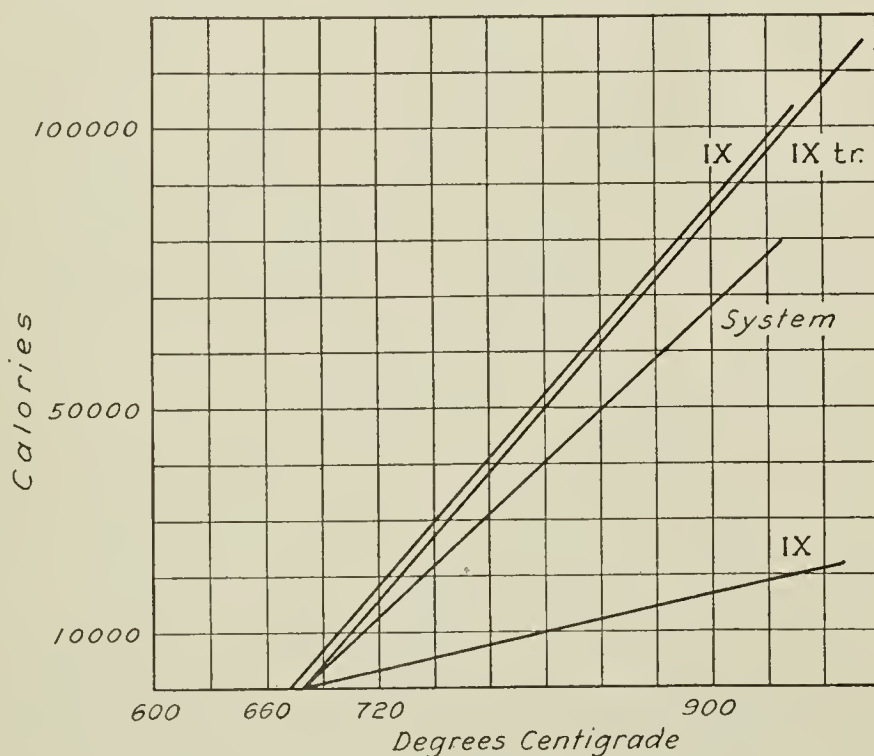


FIG. 19.—Heat capacity of A-I English china clay 216.2 grams in range 900 – 700°C . IX, 912 – $679^{\circ} = 17,500$ calories.

The heat capacity of the quartz was calculated from the results of White,¹ in Fig. 1, to give the values for one gram of quartz as represented graphically in Fig. 14. By plotting a similar curve for 251 grams of quartz, the weight used in the calibration runs, the heat capacity of the quartz between any two temperatures in the ranges 24–420°, 420–900°, 900–1200°, 1200–900°, and 900–700°, can be easily obtained and used for deriving the heat capacity of the “system.”

28. Heat Capacity of the “System.”—Several calibration runs were made with the quartz, and the net heat absorbed in raising the temperature of the quartz and the “system” through the ranges mentioned above were calculated from the data on electrical energy input, the quantity of ice water used to keep the temperature of the bath constant, and from the stirring-friction ice water correction. These results of the net heat absorbed, in all of the ranges of temperature for the calibration experiments, do not differ in duplicate runs by more than $\pm 1\%$. The steps in the calculations are very similar to those made for the clays.

The net heat absorptions obtained in each temperature range are plotted with the calculated heat absorption for the quartz, an example being given in Fig. 15. The experimental data curves are marked with Roman numerals. In most cases the initial temperatures in the various ranges covered by the calibration runs and by the experimental clay runs are different, and for calculating purposes their corresponding curves have to be transposed parallel to themselves to pass through a common origin. Such transposed curves are marked “tr” on the figures. Where distinction has to be made between ascending and descending temperature curves, they are accordingly designated “a” and “d” on the figures.

By subtracting graphically the calculated heat absorption of the quartz from the heat absorption of the combined quartz and “system,” determined experimentally, the heat capacity of the “system” is obtained, and its curve is marked accordingly.

These “system” curves are then used for obtaining the heat absorption of the clays, by subtracting them from the net heat absorption values, determined experimentally for the clays and the “system” in the requisite ranges of temperature. The resultant data are:

HEAT CAPACITY OF THE “SYSTEM”		
Temperature range	Calories	Cal. per 1°
23.560–400°	142,400	379
421–900°	170,079	355
892–1187° { ascending and descending	109,778	372
892–679°	65,317	307

¹ W. P. White, *loc. cit.*

IX. Experimental Data for the Heat Absorbed and Evolved by Clays during Firing and Cooling

29. A-1 English China Clay.—The following are the detailed experimental data and the resulting calculations for duplicate runs VI and IX, made on 247.5 grams of air dried A-I English china clay:

(a) Range 24-420°

Run	Temp. interval	Revolutions	Energy input	
			Ice water, grams	Duration in hours
VI	23.560-422°	461.30	3,086	2.93
IX	23.560-415°	452.70	2,954	2.75

The net heat energy used is then obtained:

Run	Temp. interval	Electrical	Energy in calories	
			Ice water	Net
VI	23.560–422°	238,030	45,379	192,651
IX	23.560–415°	233,594	43,956	189,638

The net heat energy absorbed is represented in Fig. 16 as the upper curves marked VI and IX. The curve marked "system" is transposed from the quartz calibration curves. By subtracting the "system" curve from the upper curves, the lower curves are obtained, these representing the heat absorbed by the clay alone. Numerically the data are:

Run	Temp. interval	Heat absorption in calories	
		Total	Per gm. per deg.
VI	23.560-422°	41,400	0.420
IX	23.560-415°	41,000	0.423
<hr/>			
Av. 0.422 ± 0.002			

(b) Range 420-900°

Run	Temp. interval	Energy input		Duration in hours
		Revolutions	Ice water, grams	
VI	422-894°	2748.00	50,956	8.33
IX	415-895°	2787.00	52,217	7.80

The net heat input is:

Run	Temp. interval	Electrical	Energy in calories	
			Ice water	Net
VI	422-894°	1,418,000	1,129,200	288,800
IX	415-895°	1,438,100	1,164,000	274,100

The curves for the net energies are given in Fig. 17. The net results differ from the average value by ±3%. The values for the heat absorbed are:

Run	Temp. interval	Heat absorption in calories	
		Total	Per gm. per deg.
VI	421-900°	121,200	1.022
IX	421-900°	103,200	0.871
<hr/>			
Av. 0.947 ± 0.075			

(c) *Range 900–1200°*

Run	Temp. interval	Revolutions	Energy input	
			Ice water, grams	Duration in hours
VIa	894–1186°	774.82	12,606	1.42
IXa	895–1187°	897.53	15,402	1.68
IXd	1187–912°	....	5,025	0.55

These results may be summarized:

Run	Temp. interval	Electrical	Energy in calories	
			Ice water	Net
VIa	894–1186°	399,810	235,410	114,400
IXa	895–1187°	463,130	349,230	113,900
IXd	1187–912°	.....	113,920	113,920

The curves corresponding to the net energy consumption are given in Fig. 18.

Between 892° and 1186° the ascending curves VIa and IXa vary only by 500 calories in 115,000, or a difference of $\pm 0.21\%$. On subtracting the heat absorption for the "system," the total heat absorptions for the clay differ by 500 calories, which now represents a difference of $\pm 4.6\%$.

The weight of the dehydrated material in run VI was 216.8 grams and in run IX 216.2 grams corresponding to losses of weight of 12.40% and 12.65%, respectively. The heat absorption and evolution are calculated per gram of air dried clay, and per gram of dehydrated clay.

Run	Temp. interval	Total	Heat absorption in calories	
			Per gram air-dried clay per deg.	Per gram dehydrated clay per deg.
VIa	892–1186°	5,700	0.078	0.089
IXa	892–1187°	5,200	0.071	0.082
			Av. 0.075	0.086
			± 0.004	± 0.004

Run	Temp. interval	Total	Heat evolution in calories	
			Per gram air-dried clay per deg.	Per gram dehydrated clay per deg.
IXd	1187–892°	12,200	0.167	0.191

(d) *Range 900–700°*

Run	Temp. interval	Energy input		
		ice water, grams	Duration in hours	Net heat in calories
IX	912–673°	4,136	0.75	90,948

The corresponding curve is given in Fig. 19:

Run	Temp. interval	Total	Heat evolution in calories	
			Per gram air dried clay per deg.	Per gram dehydrated clay per deg.
IX	912–679°	17,500	0.303	0.347

(e) *Average Heat Absorption and Heat Evolution*

To heat 1 gram of air-dried A-I English china clay from 25° to 1200° requires 644 calories.

TABLE IV

HEAT ABSORBED AND EVOLVED BY CLAY DURING FIRING AND COOLING

(For the first two clays the values given are the average results of two independent experiments and the deviations from this average are indicated)

Clay type	Loss on ignition, per cent	Heat absorbed per gram per degree on heating the air-dried (110°) clay over the temperature ranges given			Heat evolved per degree on cooling the resulting quantity of fired clay		Specific heat of the fired clay cal./gm., 1200-700°	Dehydration period	
		25-420°	420-900°	900-1200°	25-1200°	1200-900°	900-700°	Pres-sure rises 20 mm.	Pres-maximum sure pressure, falls to 3 mm.
N. Car. Kaolin.....	14.0	0.49	0.69	0.23	0.50	0.23	0.28	25°	460°
		±0.07	±0.05	±0.01	±0.035	±0.01	±0.06	to	570°
								460°	780°
A-1 English China....	12.5	0.42	0.95	0.075	0.55	0.17	0.31	25°	480°
		±0.01	±0.07	±0.004	±0.07		0.20	to	540°
								480°	760°
Tenn. Ball No. 5.....	13.8	0.47	0.53	0.51	0.51	0.20	0.33	25°	470°
								to	550°
								470°	830°
Laclede-Christy Raw Flint.....	13.0	0.47	0.68	0.24	0.50	0.17	0.37	25°	470°
								to	630°
								470°	850°
Average.....		0.46			0.51	0.19	0.32	0.24	0.27

Temp. interval	Calories
25–420°	$395 \times 0.422 \times 1.00 = 167$
420–900°	$480 \times 0.947 \times 1.00 = 455$
900–1200°	$300 \times 0.086 \times 0.87 = 22$
	Total 644

The average heat absorption per degree for A-I English china clay between 25° and 1200° is then 0.55 calories.

One gram of A-I English china clay, heated to 1200°, will evolve heat, on cooling, as follows:

Temp. interval	Calories
1200–900°	$300 \times 0.191 \times 0.87 = 50$
900–700°	$200 \times 0.347 \times 0.87 = 60$
	Total 110

or an average heat evolution of 0.22 calories per degree between 1200° and 700°.

30. Tennessee Ball Clay No. 5.—250.9 grams of air-dried clay were used, the results being given in Table IV. The heat absorbed in the ascending temperature range 900–1200° was large, part of the heat being absorbed by gaseous reactions. This assumption is substantiated by the gas pressure developed in the furnace, the foul smell of decomposed organic matter issuing from the vacuum pump, and the black appearance of the burned clay indicating organic matter.

31. North Carolina Kaolin.—Duplicate runs on 219.6 grams of clay were made, there being no unusual features to record.

32. Laclede-Christy Raw Flint Clay.—303.4 grams of clay were employed. A small gas pressure was developed in the ascending temperature range 900–1200°, probably explaining the increase in heat absorption as compared with the heat evolution in cooling over the same range of temperature.

X. Summary and Conclusions

The numerical results obtained are displayed in Table IV. They represent the data obtained for four types of clays.

33. Conclusions.—The following points and conclusions are brought out by the data presented in the table:

(1) All four clays contain approximately the same amount (14%) of moisture in the air dried condition.

(2) During the initial period of heating (up to 420°), in which all of the hygroscopic and some of the chemically combined water is driven out all of the clays absorb approximately the same amount of heat, 0.46 calories per gram per degree.

(3) Between 420° and 900° the remainder of the chemically combined water is driven out, most of it between 470° and 600° . During this period two of the clays, the North Carolina kaolin and the flint clay, show the same heat absorption, about 0.7 calorie per gram per degree. The other two clays behave differently, the English china absorbing 0.95 and the Tennessee ball only 0.53 calorie per gram per degree.

(4) During the final or finishing period 900° to 1200° , the North Carolina kaolin and the flint clay again exhibit similar behavior, each absorbing about 0.2 calorie per gram per degree. The English china clay, however, absorbs only 0.075 calorie per gram per degree over this range. Since this is less than the specific heat of the fired clay (0.17) in this temperature range, it shows that some reaction is taking place which evolves heat. Over the same range the Tennessee ball shows a heat absorption of 0.51 calorie per gram per degree and by a similar process of reasoning this clay is evidently undergoing some reaction which absorbs heat.

(5) Over the whole firing period all four clays behave alike as regards the total heat which they absorb during the firing operation, the heat absorption amounting to 0.5 calorie per gram per degree.

(6) Stated in another way, the amount of heat which must be put into the clay ware in order to completely fire it, if the finishing temperature is 1225° amounts to 1200×0.5 or 600 calories per gram of bone dry body.

(7) If, however, the heat content of the fired ware is utilized during cooling (as, for example, to heat the air for a drier) the net heat required by the various reactions which occur in the clay during the firing operation is $1200 \times (0.51 - 0.24)$ or 320 calories per gram of bone dry body; or, stated in another way, 1 gram bone dry clay at $25^{\circ} = 0.86$ gram fire clay at $25^{\circ} + 0.14$ gram water vapor at 25° —320 calories.

(8) If we subtract from these 320 calories the heat required to vaporize the 0.14 gram of water present (*i. e.*, 77 calories), the remainder, about 240 calories, represents the heat absorbed by the dehydration reaction (at room temperature to produce liquid water) plus the net heat absorbed by all of the other chemical reactions which occur during the firing (also at room temperature).

(9) The results given above supply for the first time reliable data on the heat absorption of clay in a form suitable for use in heat-balance calculations.

(10) No attempt has as yet been made to correlate the above results with the burning behavior of these clays.

The results here presented of course apply strictly only to the four clays investigated. Moreover, they should be looked upon as the initial results in an entirely new field of investigation. They represent a new type of

calorimetric work and their principal value is the indication which they give of the possibilities in this field.

Incidentally it may be pointed out that the calorimetric method developed in connection with this investigation can be used to determine the heat effects of other high temperature processes such, for example, as the heat of fusion of a glass batch or the heat absorbed in manufacturing cement clinker.

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AUTHOR INDEX TO JOURNAL

The reference number in parentheses refers to the *monthly* number of the *Journal*; the number following this is the page number. The letter O or D preceding reference number indicates that the articles are Original (O) or the material is a Discussion (D).

A list of abbreviations used in the Index is found on page 1309.

VOLUME 6

- Anderson, R. J. Metallurgical requirements of refrac., O (10) 1090.
- Arnold, H. C. The polarizing microscope as an aid in feldspar standardization, O (2) 409; Rapid means for detn. of quartz content, D (6) 704, 705.
- Arnold, R. E. An elec. fur. for vitreous enameling, D (10) 1037-1039.
- Ashley, G. H. The fire brick mat. of Pa., O (7) 837.
- Audley, J. A. The Ceram. Soc. (Eng.), O (1) 176.
- Badger, A. F. See Spencer, C. D.
- Bales, C. E. The behavior of fire brick in malleable-iron fur. bungs, D (12) 1241.
- Beecher, M. F. Developments in the manuf. of refrac. of fused alumina, O (1) 292.
- Bennett, A. L. See Wilson, H.
- Berger, E. B. See Emley, W. E.
- Binns, C. F. Clay as a medium through which ed. ideals may be presented, D (6) 769; N. Y. State School of clay-working and ceram., O (1) 90.
- Blake, A. E. Cold clean artificial gas and a discussion upon the general properties of gaseous fuels, O (7) 808; D (7) 826-28, 830.
- Bleininger, A. V. Ceram. invest. conducted by the States and the Federal Govt., O (1) 145; Glass pots and tank blocks, O (1) 248; Note on the ht. distribution in updraft kilns, O (11), 1134.
- Bole, G. A., and Stull, R. T. Use of sedimentary kaolins of Ga. in white wares, O (7) 854; See Stull, R. T.
- Booze, M. C., and Klein, A. A. A rapid means for the detn. of quartz content of feldspar, O (6) 698.
- Boudreau, J. C. Clay as a medium through which educational ideals may be effectively presented, O (6) 763; D (6) 769.
- Bouton, G. I. Refrac. for stokers, O (11) 1190.
- Bridge, L. D. An elec. fur. for vitreous enameling, D (10), 1038.
- Brown, G. H. The Ceram. Dept. at Rutgers Coll. and the State Univ. of N. J., O (1) 93.
- Brown, L. H. Fuel oil as applied to periodic updraft kilns in the manuf. of high tension elec. porcelain, O (2) 462.
- Budnikoff, P. P., and Shilov, E. A. The chemistry of the terpene medium for ceram. liquid gold, O (9) 1000.
- Buell, W. C. Some vital factors in reduction of fuel costs, O (12) 1224; D (12) 1226.
- Bunting, E. N. An elec. fur. temp. regulator, O (12) 1209.
- Burchfiel, B. M. Refrac. clays of the Alberhill, Calif. deposits, O (11) 1167.
- Burke, G. W. A rapid method for prepg. a silicate rock flux for dehydration, O (6) 761.
- Burt, S. G. Rookwood Pottery Co., O (1) 232.
- Campbell, R. M. Some investigations on kiln burning, O (8) 886.
- Carder, F. Artistic glassware, O (1) 228.
- Chapman, W. B. Producer progress during the past quarter century, O (1) 253; Recuperative fur. for the glass industry, O (1) 258; Some vital factors in reduction of fuel costs, D (12) 1226.
- Christopher, A. B. Diaspore clay of Ark. and Mo., D (3) 508.
- Clark, H. H. An elec. fur. for vitreous enameling, D (10) 1036-1039.
- Cobb, J. W. See Houldsworth, H. S.
- Comstock, G. F. Some causes of blistering of sheet steel metal enamels, O (8) 873.
- Collins, E. F. Vitreous enameling with elec. ht., O (7) 794.
- Cox, P. E. A better design for a jug mold clinch, O (12) 1230; Copper reds for the amateur, O (5) 685; Dept. of Ceram. Eng. of Iowa State Coll., O (1) 104.
- Cox, P. E., and Moulton, D. A. A new raw mat. for ceram. uses, O (8) 937.
- Crane, E. J. A brief hist. of "Chemical Abstracts," O (1) 141.
- Crawford, J. L. High alumina refrac., O (1) 290.
- Danielson, R. R., and Frehafer, M. K. The effect of some substitutes for tin oxide on the capacity of white enamels for sheet steel, O (5) 634.
- Danielson, R. R., and Sweely, B. T. The reln. between compn. and properties of enamels for sheet steel, O (10) 1011.
- Darby, W. J. See O'Harra, B. M.
- Darling, C. F. A short hist. of "Rock Products," O (1) 140.
- Davis, F. W. Outline of refrac. requirements for the iron and steel indus., O (11) 1183.
- Dawes, E. S. Some early experiences in enameling cast iron, O (1) 234.
- Douda, H. W. See Schurecht, H. G.
- Dressler, C. The artistic needs of modern faience, O (2) 398.
- Emley, W. E., and Berger, E. B. Panel tests of lime plaster, O (9) 1007.
- Endell, K. H., and Rieke, R. The progress of tech. ceram. sci. in Germany since the death of Herman Seger (1893), O (1) 196.
- Ferguson, R. F. See Howe, R. M.
- Finn, A. N. See Geller, R. F.
- Fitzgerald, G. Cold clean artificial gas, D (7) 826, 829.
- Flint, F. C. Feldspar for glassmakers, O (2) 413.
- Foster, H. D. Capping for compression specimens, O (5) 623; Effect of grog addn. on fire resist. of hollow tile, O (6) 748.

- Frederick, F. F. School of indus. art, City of Trenton, O (1) 115.
- Freeman. An elec. fur. for vitreous enameling, D (10) 1038.
- Frehafer, M. K. See Danielson, R. R.
- French, M. M. The problem of the turquoise alk. glaze, O (2) 405.
- Garve, T. W. Construction features of importance to clay plants, O (9) 961.
- Gates, W. D. Influence of the Amer. Ceram. Soc. in the terra cotta indus., O (1) 231.
- Gavin, G. P., and Hartford, F. M. A recent installation of a Harrop tunnel kiln, O (12) 1214.
- Geiger, C. F. The history of the development of silicon carbide refrac., O (1) 301.
- Geller, R. F. Progress report on specif. for refrac., O (10) 1098.
- Geller, R. F., and Finn, A. N. Further studies on cast glass pots, O (8) 865.
- Gillett, H. W. Met. requirements of refrac. for furnaces melting copper alloys, O (4) 596.
- Gorton, A. F. See Schwartz, H. A.
- Granger, A. A. The ceram. indus. of France since the end of the 19th century, O (1) 205.
- Greaves-Walker, A. F. Diaspore clays of Ark. and Mo., D (3) 507, 508.
- Greaves-Walker, A. F., and Kier, S. M. The suitability of the tunnel kiln for burning refrac., O (8) 891.
- Greer, W. R. An elec. fur. for vitreous enameling, D (10) 1037.
- Hain, V. A. An elec. fur. for vitreous enameling, D (10) 1035-37; 1038-39.
- Hall, F. P. Effect of hydrogen ion concn. upon clay suspensions, O (9) 989.
- Hammer, J. M. "The Glass Worker" and "China, Glass and Lamps," O (1) 132.
- Handy, J. O. The Pittsburgh Testing Lab. in the ceram. field, O (1) 173.
- Hardinge, H. The continuous system of grinding ceram. mat., O (3) 548.
- Harlow, J. E. Refrac. for flat arches, O (11) 1195.
- Harrington, R. F. Value of uniform fire brick from standpoint of the consumer, O (11) 1193.
- Harrison, T. R. Temperature control of Dressler tunnel kiln, O (11) 1128.
- Hartford, F. M. See Gavin, G. P.
- Heath, F. T. See Wilson, H.
- Horning, R. A. Experiences with Dutch kilns, O (9) 958.
- Hotchkiss, W. O. Geology of the Baraboo gneiss deposits, O (11) 1160.
- Hottinger, A. F. Looking backward in the terra cotta field, O (1) 306.
- Houldsworth, H. S., and Cobb, J. W. The reversible thermal expansion of refrac. mat., O (5) 645.
- Howe, R. M. Diaspore clay of Ark. and Mo., D (3) 507-9; Fire clay refrac., O (1) 275; A study of the slag test, O (2) 466; Testing of refrac., O (1) 296.
- Howe, R. M., and Ferguson, R. F. Compn. and properties of diaspore, bauxite and gibbsite, O (3) 496.
- Howe, R. M., Phelps, S. M., and Ferguson, R. F. The action of slag upon silica, magnesite, chrome, diaspore and fire clay refrac., O (4) 589.
- Hudson, C. J. How to install and operate a fuel oil system, D (2) 459.
- Insley, H. A study of the origin and cause of stones in glass, O (6) 706.
- Jaeger, F. G. An elec. fur. for vitreous enameling, D (10) 1035; Sandblast castings to be enameled, O (9) 976.
- Kier, S. M. See Greaves-Walker, A. F.
- Kimes, A. W. Hist. of the "National Glass Budget," O (1) 138; Impt. developments in the glass indus., O (1) 250.
- King, R. M. See Watts, A. S.
- Kinney, S. P. See Perrott, G. St. J.
- Kirk, H. S. Clay as medium through which ed. ideals may be presented, D (6) 769.
- Klein, A. A. A rapid means for detn. of quartz content, D (6) 704, 705; See Booze, M. C.
- Klinefelter, T. A., and Parsons, F. C. Shop notes-plaster shop, O (7) 783; Short cuts in miter cutting, O (7) 786.
- Kondo, S. Development of ceram. tech. and sci. in Japan, O (1) 212.
- Krak, J. B. "The Glass Industry," O (1) 137.
- Kriege, H. F. Effect of time and temp. upon the chlorination of flint fire clay, O (7) 850.
- Krusen, I. A. Diaspore clays of Ark. and Mo., D (3) 505.
- Kruson, J. H. Insulation of periodic kilns, O (10) 1069.
- Lalor, J. D. How to install and operate a fuel oil system, O (2) 448.
- Lapp, J. S. High voltage porcelain insulators in U. S. chronology, O (1) 315.
- Lenchner, T. Glass decorators' palette and its prepn., O (10) 1040.
- Littleton, J. T., Jr. The relative magnitude of radiation and convection hgt. in a muffle kiln, O (7) 771.
- Lowrance, R. E. See Parmelee, C. W.
- Malinovsky, A. Method of cooling enamel by compressed air, O (9) 972.
- Manion, L. W. An elec. fur. for vitreous enameling, D (10) 1037.
- Manor, J. W. A rapid means for detn. of quartz content, D (6) 704.
- Manson, M. E. The use of bentonite for suspending enamels, O (7) 790.
- Martin, J. D. Automatic kiln stokers, O (10) 1044.
- Mawby, P. Scheduling in a terra cotta plant, O (2) 440.
- McCauley, G. V. Influence of alkalies and alkaline earths on fusion temps. of the different types of refrac. clays, D (11) 1152.
- McDougal, T. G. The story of spark plug progress, O (1) 316.
- McDowell, J. S. Chrome refrac., O (1) 277; Diaspore clay of Ark. and Mo., D (3) 508; Influence of alkalies and alk. earths on fusion temps. of the different types of refrac. clays, D (11) 1151; Magnesite refrac., O (1) 280.
- McGee, E. N. Silica cement, O (8) 896; Tech. development in the field of silica refrac. during the past twenty-five years, O (1) 285.
- Minton, R. H. Sanitary ware manuf. in Amer., O (1) 319.
- Montgomery, R. J. Ophthalmic glass, a new Amer. product, O (11) 1141.
- Moulton, D. A. See Cox, P. E.
- Munsell, A. E. O. Simple method of measg. color, O (7) 777.

- Navias, L. N. Meas. of ht. absorbed and evolved by clays during firing and burning, O (12) 1268.
- Nickerson, F. P. The value of screen analysis in ceram., O (3) 563.
- Oakley, W. W. Cold clean artificial gas, D (7) 827, 828.
- O'Harra, B. M. Met. requirements for refrac. in the electrothermic met. of zinc, O (11) 1180.
- O'Harra, B. M., and Darby, W. J. The disintegration of refrac. brick by carbon monoxide, O (8) 904.
- Palmer, L. A. Tests on resistive qualities of soda-lime glasses to water, O (4) 579.
- Parmelee, C. W. History of ceram. ed. at Univ. of Ill., O (1) 97.
- Parmelee, C. W., and Lowrance, R. E. Some notes on the meas. of translucency of ceram. bodies, O (5) 630.
- Parsons, F. C. See Klinefelter, T. A.
- Pence, F. K. Tech. development in the white-ware indus., O (1) 308.
- Perrott, G. St. J., and Kinney, S. P. The meaning and microscopic meas. of av. particle size, O (2) 417.
- Phelps, S. M. See Howe, R. M.
- Pilcher, R. G. Inst. of Chemistry Glass Research Com. 1914-1922, O (1) 186.
- Poste, E. P. The relative action of acids on enamel—V, O (6) 689.
- Pyne, F. R. Met. requirements of refrac. in copper smelting and refining, O (11) 1188.
- Quine, E. Glass Research Assn., O (1) 188.
- Randall, J. E. "The Clay-Worker," a potential factor in the up-building of the ceram. indus., O (1) 120.
- Randall, T. A. The influence and achievements of the Natl. Brick Manuf. Assn. along technical lines, O (1) 224.
- Rhead, F. H. Clay as medium through which ed. ideals may be presented, D (6) 769; Some notes on hist. and modern decorative processes, O (2) 356.
- Rice, B. A. Deformation studies of silicates and aluminum silicates of the alkalis, O (3) 525.
- Richardson, W. D. Producer gas for burning refrac., O (7) 799.
- Rieke, R. See Endell, K.
- Roadhouse, R. An elec. fur. for vitreous enameling, D (10) 1038.
- Roberts, F. G. An elec. fur. for vitreous enameling, D (10) 1036-37.
- Rose, C. I. Proposed method for studying the attack of molten slags and glasses upon refrac. materials, O (12) 1242.
- Saborsky, A. D. Glass wool heat insulation in Europe, O (5) 674.
- Saxton, C. The use of wood in gas producers, O (12) 1219.
- Scholes, S. R. Substituting fuel oil for producer gas in a continuous glass tank, D (10) 1055.
- Schurecht, H. G. Clay sewer pipe manuf. I. Magnetic sepn. of iron bearing minerals from clays, O (5) 615; Clay sewer pipe manuf. II. The effect of variable alumina, silica, and iron oxide in clays and some properties of salt glazes, O (6) 717; Clay sewer pipe manuf. III. Ht. distribution in sewer pipe kilns, O (7) 831; An automatic direct reading lab. scale for weighing briquettes, O (3) 491; Tech. developments in dolomite refrac., O (1) 278;
- Schurecht, H. G., and Douda, H. W. The properties of some clay-like mat. of the bentonite type, O (8) 940; The behavior of fire brick in malleable-iron fur. bungs, O (12) 1232.
- Schwartz, H. A., and Gorton, A. F. The requirements of fire brick suited to malleable practice, O (10) 1094.
- Schwier, C. An elec. fur. for vitreous enameling, O (10) 1032; D (10) 1035-39.
- Scott, D (10) 1039.
- Sheppard, M. Zirconia refrac., O (1) 294.
- Shilov, E. A. See Budnikoff, P. P.
- Sortwell, H. H. The effect of variation in firing on the phys. properties of vitreous china bodies, O (8) 915; Impact tests on tableware, Spencer, C. D., and Badger, A. E. A skiagraphic study of fabricated glass articles, D (12) 1228; O (2) 349.
- Sproat, I. E. Effect of ht.-treatment and compn. of semi-porcelain bodies on crazing, O (3) 510.
- Spurrier, H. Further studies of porcelain glazes maturing at high temps., D (11) 1126-27.
- Staley, H. F. Developments in enameling tech. during the past twenty-five years, O (1) 240; An elec. fur. for vitreous enameling, D (10) 1038.
- Steinhoff, F. L. "Brick and Clay Record," its hist., O (1) 128; The log (twenty-five years) of progress in the brick and tile indus., O (1) 262.
- Stone, G. C. Improvements in the manuf. of zinc refrac. during the last twenty-five years, O (1) 299.
- Stout, W. The flint clay situation in Ohio, O (11) 1153.
- Stull, R. T., and Bole, G. A. Refrac. possibilities of some Ga. clays, O (5) 663; Washing tests of Georgia clays, O (6) 730; See Bole, G. A.
- Swanson, C. O. Laterite, the origin, distribution and compn. meaning of laterite, O (12) 1248.
- Sweely, B. T. An elec. fur. for vitreous enameling, D (10) 1035, 1037, 1038; See Danielson, R. R.
- Taylor, M. A. Fuel oil as adapted to the chambered continuous kiln, O (10) 1056.
- Taylor, S. The ceram. trade and its oldest paper, O (1) 118.
- Thompson, F. S. Substituting fuel oil for producer gas in a continuous glass tank, O (10) 1050.
- Thornberry, M. H. Method for analyzing diaspora clays, O (12) 1261.
- Thwing, C. B. Cold end compensation on a pyrometer system, O (10) 1062.
- Tillotson, E. W. Twenty-five years' progress in the glass indus., O (1) 244.
- Totten, G. O., Jr. Clay as medium through which ed. ideals may be presented, D (6) 769.
- Treischel, C. C. A historical sketch of the elec. porcelain indus. in Amer., O (1) 312.
- Turk, R. An elec. fur. for vitreous enameling, D (10) 1038.
- Turner, W. E. S. The Soc. of Glass Tech., O (1) 181; Teaching and research in glass tech. at the Dept. of Glass Tech., Univ. of Sheffield, O (1) 183.

- Twells, R. Jr. Further studies of porcelain glazes maturing at high temps., O (11) 1113; D (11) 1126-27; Tests on some sagger clays and bodies, O (9) 949.
- Vail, J. G. Silicate of soda in the ceram. indus., O (4) 610.
- Vollrath, C. A. W. Early history of enameling in the Vollrath Co., O (1) 237.
- Underwood, C. A. The anal. of refrac., O (12) 1263.
- Warwick, C. L. Activities of the A. S. T. M. in the field of ceram., O (1) 219.
- Washburn, E. W. Research councils, O (1) 156.
- Watts, A. S. Dept. of Ceram. Eng., Ohio State Univ., O (1) 88; Influence of alkalies and alk. earths on fusion temps. of the different types of refrac. clays, O (11) 1150; A rapid means for detn. of quartz content, D (6) 704.
- Watts, A. S., and King, R. M. The transfer of ht. through refrac. and its detn., O (10) 1075.
- Weaver, R. A. An elec. fur. for vitreous enameling, D (10) 1039.
- Weidlein, E. R. Ceram. invest. at the Mellon Inst. of Indus. Research, O (1) 167.
- Welch, F. C. Effects of accelerators and retarders on calcined gypsum, O (11) 1197.
- Wells, R. D. An elec. fur. for vitreous enameling D (10) 1035.
- Wiester, S. Air cooled *vs.* water quenched enamels, O (9) 973.
- Wikoff, A. G. "Chemical and Metallurgical Engineering," O (1) 134; Refrac. requirements for oil refining, O (11) 1176.
- Wilcox, B. Influence of alkalies and alk. earths on fusion temps. of the different types of refrac. clays, D (11) 1152.
- Williams, A. E. The mech. strength of glazing glass, O (9) 980.
- Williams, C. E. Requirements of refrac. for elec. fur., O (6) 753.
- Williams, W. S. Effect of various sizes of grog particles on clay pots, O (11) 1148.
- Williamson, J. W. Brit. Scien. Instrument Research Assn., O (1) 191.
- Wilson, H. The Ceram. Eng. Dept. of the Univ. of Wash., Seattle, O (1) 110.
- Wilson, H., Bennett, A. L., and Heath, F. T. Preliminary rept. on residual kaolin and feldspar in the Pacif. N. W., O (3) 475.
- Worcester, W. G. Canada's first ceram. school: Univ. of Saskatchewan, O (1) 107.
- Wysor, D. C. Diaspore clay of Ark. and Mo., O (3) 501; D (3) 504.

SUBJECT INDEX TO JOURNAL

- Accelerators and retarders effect of on calcined gypsum, (11) 1197.
- Air-cooled enamels, (9) 972.
- Ajax-Wyatt elec. fur., (4) 605.
- Albright, D. K., (1) 252.
- Alexander, Geo. E., (1) 189.
- Alkalies and alkaline earths, their influence on fusion temp. of different types of refrac. clays, (11) 1150.
- Allison, L. R. W., sketch of, (1) 56.
- Alumina, fused, use of in refrac., (1) 292.
refrac., (1) 290.
reversible thermal expansion of, (5) 649.
- Aluminum industry, requirements of refrac. for, (10) 1090.
silicates, deformation studies of, (3) 524.
- American Ceramic Society, origin of, (1), 10.
history of, (1), 23.
- American Chemical Society, Journal of, (1) 143.
- Analysis of clay and silica cements with fusion points, (8) 900.
of diaspore and bauxite. (3) 498; *ibid.*, (3) 503.
a rapid method for prepg. silicate rock flux for dehydration, (6) 761.
of refrac., (12) 1263.
screen value of, (3) 563.
of separates of Georgia clays, (6) 742.
- Analyzing method for diaspore clay, (12) 1261.
- Antimony in enamels, (1) 242.
- Apparatus for rapid method for prepg. silicate rock flux for dehydration, (6) 761.
for whirlpool classifier, (6) 731.
- Architectural pottery, (2) 394.
- Art, clay as a medium through which ed. ideals may be effectively presented, (6) 763.
simple method of measuring color, (7) 777.
- Artistic glassware, (1) 228.
- Ashley, H. E., sketch of, (1) 47.
- Association, N. B. M. A., (1) 224.
- Baily electric brass furnaces, (4), 600.
- Bain, H. Foster, (1) 148.
- Baraboo ganister deposits geology of, (11) 1160.
- Barringer, L. E., sketch of, (1) 40.
- Bauxite and bauxitic clays, (5) 665.
compn. of Ark. and Ala., (12) 1259.
diaspore and gibbsite compn. and properties of, (3) 496.
relationship to laterite, (12) 1257.
- Bauxitic clay, thermal expansion of, (5) 647.
- Beatty, Nevada, clay, a new raw mat. for ceramic uses, (8) 939.
- Beecher, M. F., sketch of, (1) 54.
- Bentonite chem. anal. of, (8) 942.
the properties of some claylike mat., (8) 940.
the use of, for suspending enamels, (7) 790.
- Berdel, Eduard, (1), 198.
- Binns, C. F., sketch of, (1) 23.
- Bleining, A. V. sketch of, (1) 24.
- Blizard, John, (1) 154.
- Blistering, causes of in sheet steel enamels, (8) 873.
- Bloomfield, C. A., (1) 87.
- Bole, Geo. A., (1) 154.
- Books, ceramic, ref. list of, (1) 322.
- Bowman, O. O., 2nd, sketch of, (1) 58.
- Brick, A. S. T. M., (1) 219.
and Clay Record, (1) 128.
- National Manufacturers Association, (1) 224
- portable conveyors for unloading from kilns, (1) 271.
- setting machines, first development in, (1) 264.
- storage battery lift truck for handling, (1) 273.
- Bricks, old hand methods, (1) 269.
- British Scientific Instrument Research Association, (1) 191.
- Brown, Charles W., (1) 251.
- Brown, Geo. H., sketch of, (1) 41.
- Bureau of Mines, (1) 152.
of Standards, (1) 147.
- Burning (see firing).
refrac. with producer gas, (7) 799.
some invest., (8) 886.
- Burt, S. G., sketch of, (1) 24.
- By-product coke industry, silica brick used in, (1) 287.
- Calorimeter for measg. ht. absorbed and evolved by clays, (12) 1281.
- Calorized tubes in recuperators, (12) 1225.
- Cannan, W. J., sketch of, (1) 50.
- Capping for compression specimens, (5) 623.
- Carbon effect on refrac., (11) 1182.
monoxide, disintegration of refrac. brick by, (8) 904.
and sulphur in clays, ht. effect of, (12) 1276.
- Carborundum brick, effect of carbon monoxide on, (8) 913.
reversible expansion of, (5) 649.
- Cast glass pots, (8) 865.
- Cement, silica, (8) 896.
- Cements, zirconia, (1) 295.
- Ceramic books, ref. list of, (1) 322.
ed. schools, Japan, (1) 214.
industries, classification of, (1) 68.
description of, (1) 75.
growth of, (1) 71.
progress during the war, (1) 81.
in France, (1) 205.
investigations by the State and Federal government, (1) 146.
lit. Ger., (1) 204.
research in France, (1) 211.
Japan, (1) 213.
schools, (1) 84.
in Ger., (1) 203.
sculpture, (2) 390.
Society (English), (1) 176.
Ger., (1) 197.
Japan, (1) 213.
tech. in Japan, (1) 212.
- Ceramics, definition of, (1) 67.
- Charter Members, (1) 23-35.
- Chemical Abstracts, (1) 141.
analysis and fusion points of fire clay and silica cements, (8) 900.
of refrac., reln. to properties of refrac., (10) 1110.
of separates of Ga. clays obtained in whirlpool separator, (6) 742.
compn. of Baraboo ganister, (11) 1165.
of Ga. clays, (5) 665.
reln. of refractoriness to, (5), 665.
and Metallurgical Engineering, (1) 134.
- China, Glass and Lamps, (1) 132.
vitreous bodies, effect of variation in firing on properties of, (8) 915.

- Chlorination of flint fire clays, effect of time and temp. upon, (7) 850.
- Chrome brick, effect of carbon monoxide on, (8) 913.
refrac., (1) 277.
action of slags upon, (4) 589.
- Clare, R. L., sketch of, (1) 55.
- Clark, W. M., sketch of, (1) 58.
- Classifier, whirlpool, (6) 731.
- Clause, W. L., (1) 252.
- Clay, flint situation in Ohio, (11) 1153.
as a medium through which ed. ideals may be effectively presented, (6) 763.
plants, construction features of importance, (9) 961.
products, heavy, Japan, (1) 214.
suspensions, effect of hydrogen ion concn. upon, (9) 989.
settling of, (9) 992.
- Clays, flint, chlorination of, (7) 850.
Ga. washing test of, (6) 730.
of Pa., (7) 842.
refrac., Alberhill, Calif., (11) 1167.
- Clayworker, (1) 120.
- Coke oven, thermal expansion of silica brick after use in, (5) 655.
- Colloid, effect of hydrogen ion concn. upon clay suspensions, (9) 989.
- Color, simple method of meas., (7) 777.
- Compression strength of enamels, (10) 1017.
- Copper red, for the amateur, (5) 685.
glazes, (5) 685.
- Cornwall stone, a new raw mat. substitute for, (8) 939.
- Cox, Paul E., sketch of, (1) 105.
- Cramer, Eduard, sketch of, (1) 199.
- Crazing on semi-porcelain, effect of ht. treatment and compn., (3) 510.
- Crockery and Glass Journal, (1) 118.
- Danielson, R. R., sketch of, (1) 52.
- Decorative processes, architectural pottery, (2) 394.
incised, etched and carved, (2) 358.
luster, (2) 389.
modeled relief, (2) 360.
monochromes, (2) 384.
notes on, historical and modern, (2) 356.
overglaze, (2) 390.
polychrome glaze, (2) 376.
sculpture, (2) 390.
slip, (2) 363.
underglaze, (2) 367.
- Decorators' palette and its prepn. for glass, (10) 1040.
- Definition of ceram., (1) 67.
- Deformation studies of silicates and aluminium silicates of the alkalis, (3) 525.
- Detroit elec. fur., (4) 602.
- Devitrification, stones in glass, (6) 707.
- Diaspore, bauxite and gibbsite, compn. and properties of, (3) 496.
- Diaspore clays, of Ark. and Mo., (3) 501.
method for analyzing, (12) 1261.
of Mo., (3) 505.
refrac. action of slags upon, (4) 589.
- Dissociation of N. Car. kaolin, press. developed by, (12) 1275.
- Dolomite refrac., (1) 278.
- Drain tile, A. S. T. M., (1) 221.
- Dressler tunnel kiln (Bradford), (1) 265.
temp. control of, (11) 1128.
- Dutch kilns, experience with, (9) 958.
- Educational ideals effectively presented through clay as a medium, (6) 763.
- Electric fur., Ajax-Wyatt, (4) 605.
Baily, (4) 600.
Detroit, (4) 600.
refrac., requirements for, (6) 753.
temp. regulator, (12) 1209.
ht. for vitreous enamel, (7) 794.
for vitreous enameling, (10) 1030.
- Electrical porcelain, historical sketch of, (1) 312.
- Elutriation, comparison with microscopic meas., (2) 433.
- Enamel, Division, formation of, (1) 243.
fish scaling, (1) 244.
in Japan, (1) 217.
relative action of acids on, (6) 689.
sandblasting castings, (9) 976.
- Enameled plates, resist. of to acetic acid, (10) 1027.
resist. to impact, (10) 1021.
- Enameling, automatic dredge, (1) 241.
cast iron, (1) 204.
decorative, of cast iron, (1) 242.
development of tech. of, (1) 240.
elec. fur. for, (10) 1030.
with elec. ht., (7) 794.
machine molding of bath tubs., (1) 241.
Vollrath Co., (1) 237.
- Enamels, antimony in, (1) 242.
compressive strength of, (10) 1017.
cooling by compressed air, (9) 972.
effect of some substitutes for tin oxide on opacity of white, for sheet steel, (5) 634.
expansivity of, (10) 1017.
for sheet steel, the reln. between compn. and properties of, (10) 1011.
sheet steel, causes of blistering, (8) 873.
the use of bentonite for suspending, (7) 790.
- Endell, K. H., sketch of, (1) 199.
- Experiment Stations, Ger., (1) 203.
- Expansivity of enamels, (10) 1017.
- Faience, artistic needs of, (2) 398.
- Farnham, D. T., sketch of, (1) 50.
- Farren, Mabel C., sketch of, (1) 51.
- Faugeron, Gabriel, (1) 205.
- Feldspar deposits, Pacific Northwest, (3) 482.
for glass makers, (2) 413.
rapid means for detn. of quartz content, (6) 698.
specif. for glass, (2) 414.
standardization use of polarizing microscope, (2) 409.
- Fieldner, A. C., (1) 154.
- Fire brick in malleable-iron fur. bungs, (12) 1232.
requirements of, for malleable practice, (10) 1094.
- Fire clay refrac., (1) 275.
action of slags upon, (4) 589.
reversible thermal expansion of, (5) 648.
- Firing (see burning).
and cooling, meas. of ht. absorbed and evolved, (12) 1268.
effect of variation of on phys. properties of vitreous china bodies, (8) 915.
kiln, some investigations of, (8) 886.
- Fiske, J. Parker B., sketch of, (1) 25.
- Flint clay situation in Ohio, (11) 1153.
- Flint fire clays, chlorination of, (7) 850.
of Pa., (7) 842.

- phys. properties of, (7) 348.
Ford, J. B., (1) 251.
France, ceramic industry of, (1) 205.
ceramic publications, (1) 211.
research, (1) 211.
porcelain, (1) 209.
pottery, (1) 206.
refrac., (1) 206.
stoneware, (1) 208.
Frink, Robt. L., (1) 189.
Fuel costs, some vital factors in reduction of, (12) 1224.
Fuel gases, general properties of, (7) 808.
Fuel oil, as adapted to the chambered continuous kiln, (10) 1056.
how to instal and operate a system, (2) 448.
in periodic kiln, (2) 462.
substituting for producer gas in a continuous glass tank, (10) 1050.
system on Harrop tunnel kiln, (12) 1217.
Fuel, wood for, in gas producer, (12) 1219.
Furnace, elec. for vitreous enameling, (10) 1030.
- Ganister, geology of the Baraboo deposits, (11) 1160.
in Pa., (7) 845.
Gas, control in Dressler tunnel kiln, (11) 1128.
producer, Chapman, (1) 257.
Hughes, (1) 254.
Morgan, (1) 256.
use of wood in, (12) 1219.
Wood, (1) 255.
progress during past quarter century, (1) 253.
Gates, W. D., sketch of, (1) 25
Geijsbeek, S., sketch of, (1) 26.
Geology of the Baraboo ganister deposits, (11) 1160.
Georgia clays, refrac. properties of, (5) 662.
washing test of, (6) 730.
sedimentary kaolins use of, (7) 854.
German ceram. lit., (1) 204.
Society, (1) 197.
Germany, progress of ceram. sci. in, (1) 196.
Gibbsite, bauxite and diaspore compn. and properties of, (3) 496.
Glass advance in chem. tech. of, (1) 246.
articles, skiagraphic study of, (12) 1228.
clear crown, (11) 1141.
decorator's palette and its prepn., (10) 1040.
development of mech. appliance for, (1) 246.
flint, (11) 1142.
glazing mech. strength of, (9) 980.
industry, (1) 137.
important developments in, (1) 250.
recuperative fur. for, (1) 258.
twenty-five yrs. progress, (1) 244.
in Japan, (1) 217.
makers, feldspar for, (2) 413.
ophthalmic, a new Amer. product, (11) 1140.
origin and cause of stones in, (6) 706.
pots, cast, (8) 865.
compn. of, (8) 867.
and tank blocks, (1) 248.
Research Assn., (1) 188.
tank, substituting fuel oil for producer gas in, (10) 1050.
wool heat insulation in Europe, (5) 676.
Glass Worker, The, (1) 132.
Glasses, goggle, (11) 1144.
tests of resistive qualities of soda-lime, (4) 579.
Glassware, artistic, (1) 228.
- Glaze, salt, effect of variable alumina, silica and iron oxide in clays on properties of, (6) 717.
turquoise alkaline, (2) 405.
Glazes, porcelain maturing at high temp., (11) 1113.
for semi-porcelain, (3) 514.
Glazing glass, mech. strength of, (9) 980.
Gold, the chemistry of the terpene medium for ceram. liquid, (9) 100.
Gorton, A. F., sketch of, (1) 59.
Gorton, E. E., sketch of, (1) 26.
Grain size, microscopic meas. of av., particle size, (2) 417.
Granger, A. A., (1) 205.
Greaves-Walker, A. F., sketch of, (1) 43.
Greenough, M. B., picture of, (1) 54.
Grinding ceram. mat. continuous system of, (3) 548.
Grog for cast glass pots, (8) 867.
effect of additions on fire resist. of hollow tile, (6) 748.
particles, the effect of various sizes of on clay pots, (11) 1148.
for saggers, (9) 951.
Gypsum, calcined, effect of accelerators and retarders on, (11) 1197.
- Handy, J. O., picture of, (1) 173.
Hardinge Mills, continuous system of grinding, (3) 548.
Harvey, F. A., sketch of, (1) 55.
Heat absorbed and evolved by clays during firing and cooling, (12) 1268.
distribution in updraft kilns, note on, (11) 1134.
in sewer pipe kilns, (7) 831.
transfer and its detn., (10) 1075.
Heats of reaction of clays at high temps., (12) 1272.
Heavy clay products, construction features, of importance, (9) 961.
Japan, (1) 214.
twenty-five years' progress in, (1) 262.
Hecht, Herman, (1) 200.
Heinecke, A., (1) 196.
Hepplewhite, J. W., sketch of, (1) 60.
Hice, R. R., picture of, (1) 40.
History of the American Ceramic Society, (1) 2.
Hollow Building Tile, A. S. T. M., (1) 223.
Hollow tile, effect of additions on fire resist., (6) 748.
Hope, Herford, sketch of, (1) 46.
Hostetter, J. C., sketch of, (1) 54.
Hottinger, A. F., sketch of, (1) 46.
Howe, R. M., sketch of, (1) 45.
Humphrey, H. P., sketch of, (4) 49.
Hursh, R. K., sketch of, (1) 44.
Hull, W. A., sketch of, (1) 57.
Hydrogen ion concn. measurement of, (9) 989.
effect of concn. upon clay suspensions, (9) 989.
- Illinois, Univ. of, ceram. dept., (1) 97.
Impact, resist. of enameled plates to, (10) 1021.
Impact test on table ware, (2) 349.
Institute of Chemistry, Glass Research Comm., (1) 186.
Insulation, glass wool, (5) 676.
of periodic kilns, (10) 1069.
Iowa State College, ceram. dept., (1) 104.
Iron bearing minerals, magnetic sepn. from clays, (5) 615.
- Jaeger, F. G., sketch of, (1) 60.
Japan, ceramic, research, (1) 213.

- Society, (1) 213.
 tech., (1) 212.
 Japan, ed. institutions, (1) 214.
 enamel in, (1) 217.
 glass in, (1) 217.
 heavy clay products, (1) 214.
 pottery, (1) 216.
 refrac., (1) 215.
 Johnston, J. R., (1) 250.
 Jour. of the Amer. Chem. Soc., (1) 143.
 Jour. of Indus. and Eng. Chemistry, (1) 142.
 Journals, Ceram., (1) 118.

 Kaolin, residual, Pacific Northwest, (3) 475.
 Kaolins, sedimentary, Ga. use of in whitewares, (7) 854.
 test of, Pacific Northwest, (3) 485.
 Keppeler, G., (1) 200.
 Kerr, C. H., sketch of, (1) 57.
 Kiln, automatic stokers, (10) 1044.
 burning investigations, (8) 886.
 chambered, fuel oil adapted to, (10) 1056.
 Dressler tunnel, temp. control of, (11) 1128.
 Harrop tunnel, a recent installation, (12) 1214.
 muffle, the relative magnitude of radiation and convection htg. in., (7) 771.
 periodic, use of fuel oil in, (2) 462.
 updraft, ht. distribution in, (11) 1134.
 Kilns, Dutch experience with, (9) 958.
 insulation of, (10) 1069.
 sewer pipe, ht. distribution in, (7) 831.
 tunnel, for burning refrac., (8) 891.
 Kimes, A. W., (1) 139.
 Kimes, G. B., (1) 139.
 Kirk, H. L., sketch of, (1) 52.
 Klinefelter, T. A., sketch of, (1) 59.
 Koerner, J., (1) 201.
 Kraze, F., (1) 201.

 Laboratory, weighing scale, automatic direct reading, (3) 491.
 Landrum, R. D., sketch of, (1) 47.
 Langenbeck, Karl, sketch of, (1) 27.
 Laterite, origin, distribution and compn. of, (12) 1248.
 Lovejoy, Ellis, sketch of, (1) 27.
 Lime plaster, panel tests of, (9) 1007.
 Luster, processes, (2) 389.
 Lyon, D. A., sketch of, (1) 153.

 Magnesia, reversible thermal expansion of, (5) 649.
 Magnesite brick, effect of carbon monoxide on, (8) 912.
 refrac., (1) 280.
 action of slags upon, (4) 589.
 Magnetic sepn. of iron bearing minerals in clay, (5) 615.
 Malleable practice, the requirements of fire brick suited to, (10) 1094.
 Mayer, Ernest, sketch of, (1) 28.
 Maynard, T. Poole, sketch of, (1) 59.
 McCullough, E. W., (1) 161.
 McDowell, J. S., sketch of, (1) 55.
 Mechanical strength of glazing glass, (9) 980.
 Mellon Institute, (1) 167.
 Metallurgical requirements of refrac. for aluminum industry, (10) 1090.
 Microscopic measurement compared with elutriation, (2) 433.
 of particle size, (2) 417.
 Minton, L. H., sketch of, (1) 42.
 Mitre cutting, short cuts in, (7) 786.

 Mold clinch, a better design for a jug, (12) 1230.
 Monro, W. L., (1) 253.
 Montgomery, E. T., sketch of, (1) 49.
 Moore, R. B., (1) 153.
 Mueller, H. C., sketch of, (1) 29.

 National Glass Budget, (1) 138.
 New York State School of Clay-Working and Ceram., (1) 90.
 North Dakota, ceram. dept., (1) 110.
 Newcomb College, ceram. dept., (1) 117.

 Officers, history of personnel, Amer. Ceram. Soc., (1) 35.
 Ohio State University, ceram. dept., (1) 88.
 Oil, as adapted to the chambered continuous kiln, (10) 1056.
 fuel, how to install and operate, (2) 448.
 in periodic kiln, (2) 462.
 refining, refrac. requirements, (11) 1176.
 substituting for producer gas in a continuous glass tank, (10) 1050.
 Opacifiers, in white enamel for sheet steel, (5) 635.
 in sheet steel enamel, classification of, by reflecting power, (5) 636.
 Ophthalmic glass, a new American product, (11) 1140.
 Origin of Amer. Ceram. Soc., (1) 2.
 Orton, Edward, Jr., sketch of, (1) 30.

 Parmelee, C. W., sketch of, (1) 39.
 Pass, James, sketch of, (1) 31.
 Pence, F. K., sketch of, (1) 43.
 Pennsylvania, fire brick mat., (7) 837.
 Pilcher, R. G., Institute of Chemistry, Glass Research Comm., (1) 186.
 Pittsburgh Testing Lab., (1) 173.
 Plaster shop, notes, (7) 783.
 Polychrome glaze processes, (2) 376.
 Porcelain, elec., historical sketch of indus., (1) 312.
 France, (1) 209.
 glazes maturing at high temps., (11) 1113.
 high voltage insulators, (1) 315.
 sanitary, manuf. in Amer., (1) 319.
 semi, body compn., (3) 516.
 semi, effect of ht. treatment and compn. on crazing, (3) 510.
 semi, glaze for, (3) 514.
 spark plugs, (1) 316.
 Porosity, effect of on thermal expansion of fire clay, (5) 649.
 reln. to serviceability of fire brick, (12) 1238.
 Poste, E. P., sketch of, (1) 53.
 Pots, cast, glass, (8) 865.
 clay, the effect of various sizes of particles on, (11) 1148.
 Pottery, architectural, (2) 394.
 in France, (1) 206.
 Japan, (1) 216.
 Rookwood, (1) 232.
 Producer gas for burning refrac., (7) 799.
 cold clean gas, (7) 808.
 substituting oil for, in a continuous glass tank, (10) 1050.
 Products, value of, (1) 69.
 Properties of some clay-like mat. of bentonite type, (8) 940.
 Publications, ceramic in France, (1) 211.
 Pukall, Wilhelm, (1) 202.
 Purdy, Ross C., sketch of, (1) 38.
 Purington, D. V., (1) 87.
 Pyrometer system, cold end compensation on, (10) 1062.

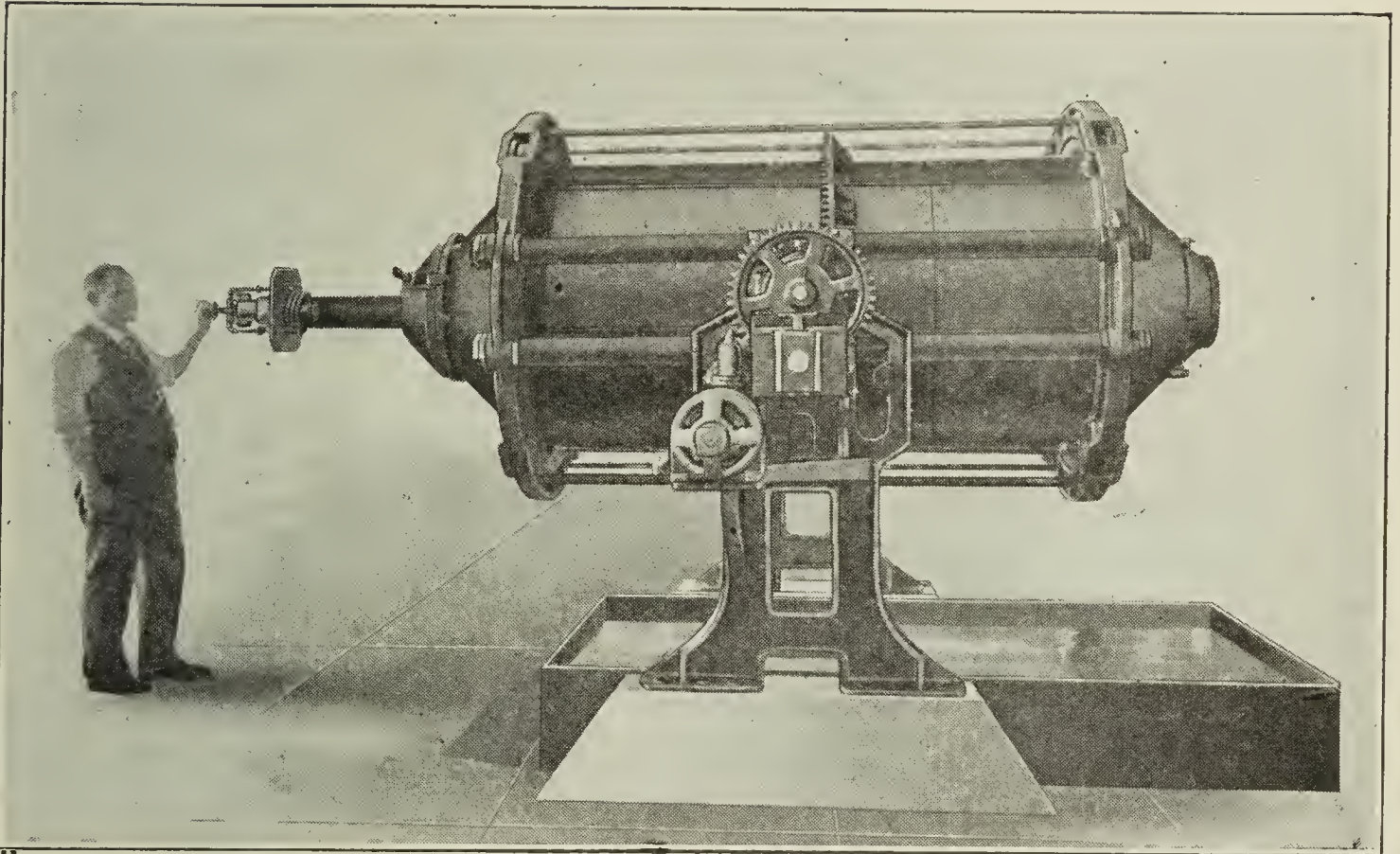
- Quine, Edward, (1) 188.
 Quartzite, expansion curve for, (5) 651.
- Radiation and convection, relative magnitude of
 in htg. a muffle kiln, (7) 771.
- Randall, J. E., (1) 121.
 Randall, T. A., (1) 87.
- Recuperators as fuel economizers, (12) 1224.
- Red glazes, copper, (5) 685.
- Reflection values, detn. of different opacifiers in
 sheet steel enamels, (5) 640.
- Refractories, reln. of chem. compn. to, (5) 665.
- Refractory brick, disintegration of by carbon
 monoxide, (8) 904.
 clays of Alberhill, Calif., (11) 1167.
 clays of Ga., (5) 662.
 clays, influence of alkalies and alkaline earths
 on fusion temp., (11) 1150.
 fire brick mat. of Penn., (7) 837.
 mat., the reversible thermal expansion of, (5)
 645.
 requirements for the iron and steel indus., (11)
 1183.
 requirements for oil refining, (11) 1176.
 slag test, (2) 466.
- Refractories, action of slag upon silica magnesite,
 chrome, diaspore and fire clay, (4) 589.
 anal. of, (1) 1263.
 A. S. T. M., (1) 222.
 chrome, (1) 277.
 dolomite, technical developments in, (1) 278.
 effect of carbon on, (11) 1182.
 fire brick in malleable-iron fur. bungs, (12)
 1232.
 fire clay, (1) 275.
 for flat arches, (11) 1195.
 in France, (1) 206.
 fused alumina, (1) 292.
 geol. of the Baraboo ganister deposits, (11)
 1160.
 high alumina, (1) 290.
 Japan, (1) 215.
 magnesite, (1) 280.
 mats., method for studying attack of molten
 slags and glasses upon, (12) 1242.
 metallurgical requirements of, in aluminum in-
 dustry, (10) 1090.
 for fur. melting copper alloys, (4) 589.
 for metallurgy of zinc, (1) 299.
 producer gas for burning, (7) 799.
 requirements of in copper smelting and refin-
 ing, (11) 1188.
 requirements for elec. fur., (6) 753.
 requirements for in electrothermic metallurgy
 of zinc, (11) 1180.
 requirements of, for malleable practice (10),
 1094.
 silica, (1) 285.
 silicon carbide, (1) 301.
 specif. for, (10) 1098.
 for stoker, (11) 1190.
 suitability of tunnel kiln for burning, (8) 891.
 testing of, (1) 296.
 transfer of ht. through and its detn., (10) 1075.
 value of uniform fire brick from the stand-
 point of the consumers, (11) 1193.
 zirconia, (1) 294.
- Research, ceram. Japan, (1) 213.
 councils, (1) 156.
- Richardson, W. D., sketch of, (1) 32.
- Rhead, F. H., sketch of, (1) 51.
- Riddle, F. H., sketch of, (1) 43.
- Rieke, Reinhold, (1) 202.
- Ries, H., sketch of, (1) 32.
- Rock Products, (1) 140.
- Rockwood, N. C., (1) 140.
- Rolfe, C. W., (1) 98.
- Rookwood Pottery, (1) 232.
- Rutgers College, ceram. dept., (1) 93.
- Sagger clays and bodies, (9) 949.
- Salisbury, B. E., sketch of, (1) 44.
- Salt glazes, effect of variable alumina, silica, iron
 oxide in clays, (6) 717.
- Sandblasting castings to be enameled, (9) 976.
- Sanitary ware manufd. in Amer., (1) 319.
- Saskatchewan, Univ. of, ceram. dept., (1) 107.
- Saxe, C. W., sketch of, (1) 60.
- Schools, Ceram., in Ger., (1) 203.
 in Japan, (1) 214.
- Schurecht, H. G., (1) 172.
- Screen anal., value of in ceram., (3) 563.
 of Ga. sedimentary kaolins, (7) 856.
- Sevres, manuf. of, (1) 209.
- Sewer pipe, A. S. T. M., (1) 220.
 manuf., (5) 615, (6) 717, (7) 831.
- Shale planer, (1) 267.
 preliminary crusher, (1) 272.
- Shaw, J. B., sketch of, (1) 56.
- Silica brick, by product coke ovens, (1) 287.
 development in, manuf. of, (1) 288.
 effect of carbon monoxide on, (8) 912.
 geol. of the Baraboo ganister deposits, (11)
 1160.
 thermal expansion of, (5) 653.
- Silica, cement, (8) 896.
 refrac., tech. development in, (1) 285.
 action of slag upon, (4) 589.
- Silicate of soda in ceram. indus., (4) 610.
- Silicates, deformation studies of, (3) 524.
- Silicon carbide, refrac., (1) 301.
 reversible expansion of, (5) 649.
- Silverman, A., sketch of, (1) 61
- Skiagraphic study of fabricated glass articles, (12)
 1228.
- Slag, action of upon silica, magnesite, chrome,
 diaspore and fire clay refrac., (4) 589.
 test of refrac., (2) 466.
- Slags, anal. and m. p., (2) 467.
 and glasses, method for studying attack of,
 on refrac. mat., (12) 1242.
- Society, Amer., for Testing Mat., (1) 219.
 of glass tech., (1) 181.
- Soda-lime glasses resistive qualities, (4) 579.
- Spalling losses of fire brick in reln. to deforma-
 tion under load, (12) 1239.
 of fire brick, reln. to service, (12) 1234.
 and porosity reln. to serviceability of fire
 brick, (12) 1235.
 and the RO and R₂O₃ ratios in fire brick, (12)
 1236.
- Spalling, reln. of in firing temps. and fineness of
 grain of fire clay in, (12) 1240.
- Spark plug porcelains, (1) 316.
- Specific ht., data for calibrating calorimeter, (12)
 1271.
 exptl. data necessary for, (12) 1283.
 of refrac. mat., (12) 1269.
- Specifications, feldspar, (2) 414.
 for refrac., (10) 1098.
- Spectrophotometric app. for detg. reflection
 values of opacifiers in sheet steel enamels,
 (5) 640.
- Staley, H. F., sketch of, (1) 41.
- Standardization of feldspar, use of polarizing mi-
 croscope, (2) 409.

- Steel, sheet, causes of blistering of enamels on, (8) 873.
 the reln. between compn. and properties of enamels for, (10) 1011.
- Steger, Walter F., (1) 202.
- Stokers, automatic kiln, (10) 1044.
 mech. for periodic kilns, (1) 268.
 refrac. for, (11) 1190.
- Stones, batch, (6) 710.
 devitrification, (6) 707.
 in glass origin and cause of, (6) 706.
 pot or tank, (6) 712.
- Stoneware, France, (1) 208.
- Stover, Edward C., sketch of, (1) 33.
- Stratton, S. W., (1) 148.
- Stull, R. T., sketch of, (1) 42.
- Sulphur and carbon in clays, ht. effect of, (12) 1276.
- Sweely, B. T., sketch of, (1) 45.
- Tableware, impact tests on, (2) 349.
- Tefft, C. F., sketch of, (1) 54.
- Temperature control of temp. in Dressler tunnel kiln, (11) 1128.
 regulator for elec. fur., (12) 1209.
- Terpene, the chemistry of for medium for ceram. gold, (9) 1000.
- Terra cotta indus., (1) 231.
 review of, (1) 306.
 scheduling in, (2) 440.
- Test, rapid method for detg. quartz content of feldspar, (6) 698.
 slag, for refrac., (2) 466.
 accelerated, (12) 1243.
 transfer of ht. through refrac., (10) 1075.
- Testing Materials, Amer. Soc. of, (1) 219.
- Tests, capping for compression specimens, (5) 623.
 compressive strength of enamels, (10) 1017.
 control of refrac., (10) 1099.
 effect of carbon monoxide on refrac. brick, (8) 907.
 endurance of refrac., (10) 1101.
 expansivity of enamels, (10) 1017.
 on fire brick, (12) 1233.
 flint clays of Pa., (7) 848.
 Ga. sedimentary kaolins, (7) 856.
 impact of enameled plates, (10) 1021.
 on tableware, (2) 349.
 kiln burning, (8) 886.
 meas. of translucency of ceram. bodies, (5) 630.
 mech. strength of glazing glass, (9) 980.
 for opacifying valucs in sheet steel enamels, (5) 634.
 panel tests of lime plaster, (9) 1007.
 of refrac. for specif., (10) 1098.
 of resist. of enameled plates to acetic acid, (10) 1027.
 on resistive qualities of soda-lime glasses, (4) 579.
 service and lab. tests of Ga. clays, (5) 663.
 on some sagger clays and bodies, (9) 949.
 spectrophotometric app., (5) 640.
 suitability of refrac., (10) 1099.
- Thermal anal. of N. Car. kaolin, (12) 1274.
 expansion in refrac., (5) 645.
 expansion, reversible, of refrac. mat., (5) 645.
- Tillotson, E. W., sketch of, (1) 46.
- Tin oxide, effect of some substitutes for on opacity of enamels for sheet steel, (5) 634.
- Translucency of ceram. bodies, meas. of, (5) 630.
- Treischel, C. C., sketch of, (1) 56.
- Trenton School of Indus. Arts, (1) 115.
- Tunnel kilns for bunning refrac., (8) 891.
 a recent installation of a Harrop, (12) 1214
- Turquoise alkaline glaze, (2) 405.
- Universities, ceram. courses in, (1) 87.
- University of Sheffield glass research in, (1) 183.
- Updraft kilns, note on the ht. distribution in, (11) 1134.
- U. S. Chamber of Commerce, (1) 160.
- U. S. Geol. Survey, (1) 146.
- Vitreous china bodies, effect of variation of firing on phys. properties of, (8) 915.
- Walker, F. W., sketch of, (1) 33.
- Wall and floor tile, compn., (7) 859.
- Washburn, E. W., sketch of, (1) 48.
- Washington, University of, ceram. dept., (1) 110.
- Waste ht., (12) 1224.
- Watts, Arthur S., sketch of, (1) 39.
- Weelans, Charles, sketch of, (1) 38.
- Weidlein, E. R., picture of, (1) 167.
- Wheeler, H. A., sketch of, (1) 34.
- Whitewares indus., tech. development in, (1) 308.
 use of sedimentary kaolins of Ga. in, (7) 854.
- Williams, A. E., sketch of., (1) 53.
- Wilson, Hewitt, picture of, (1) 111.
- Wilson, Thomas E., picture of, (1) 224.
- Wood, use of in gas producers, (12) 1219.
- Worcester, W. G., (1) 107.
- Zimmer, W. H., sketch of, (1) 35.
- Zinc, refrac. for, (1) 299.
 requirements for refrac. in the electrothermic metallurgy of, (11) 1180.
- Zirconia Brazilian oxide anal. of, (1) 295.
 cements, (1) 295.
 refrac., (1) 294.

ABBREVIATIONS USED IN INDEX

abs.	absolute	detn.	determination
a. c.	alternating current	dil.	dilute
alk.	alkaline		
amt.	amount	econ.	economical
anal.	analysis	ed.	educational
anhyd.	anhydrous	elec.	electric, electrical
app.	apparatus	e. m. f.	electromotive force
approx.	approximate, approximately	equil.	equilibrium
at. wt.	atomic weight	equiv.	equivalent
av.	average	est.	estimate
		estd.	estimated
b. p.	boiling point	estg.	estimating
B. t. u.	British thermal units	estn.	estimation
bldg.	building	evap.	evaporate
Brit.	British	evapd.	evaporated
		evapg.	evaporating
cal.	calory(ies)	evapn.	evaporation
calc.	calculate	examd.	examined
calcd.	calculated	examg.	examining
calcg.	calculating	examn.	examination
calcn.	calculation	expt.	experiment
Can.	Canada	exptl.	experimental
cc.	cubic centimeters	ext.	extract
ceram.	ceramics	extd.	extracted
charac.	characteristics	extg.	extracting
chem.	chemical (not chemistry)	extn.	extraction
cm.	centimeter(s)		
circ.	circular	f. p.	freezing point
Co.	Company	ft.	foot, feet
Comm.	Committee	fund.	fundamental
coeff.	coefficient	fur.	furnace
compd.	compound		
compn.	composition	gen.	general
concd.	concentrated	g.	gram(s)
concn.	concentration		
condy.	conductivity	htg.	heating
const.	constant	h. p.	horsepower
contd.	contained	hr.	hour
contg.	containing		
C. P.	chemically pure	in.	inch(es)
cryst.	crystalline (not crystallize)	indus.	industrial
crystd.	crystallized	inorg.	inorganic
cu. m.	cubic meter(s)	insol.	insoluble
		invest.	investigation
d.	density		
d. c.	direct current	kg.	kilogram(s)
decompn.	decomposition	kw.	kilowatt(s)
det.	determine		
detd.	determined	l.	liter(s)
detg.	determining	lab.	laboratory

lb.	pound(s)	prob.	problem
lit.	literature		
		qual.	qualitative
mach.	machinery, machine	quant.	quantitative
mat.	material		
met.	metallurgy, metallurgical	recrystd.	recrystallized
m.	meter(s)	ref.	reference
manuf.	manufacture	refrac.	refractory
max.	maximum	rept.	report
mfg.	manufacturing	resist.	resistance
meas.	measure, measurement	resis.	resisting
mech.	mechanical	resp.	respectively
mg.	milligram	r. p. m.	revolutions per minute
min.	minute(s)		
mixt.	mixture	sat.	saturate
mol.	molecule, molecular	satd.	saturated
mol. wt.	molecular weight	satg.	saturating
m. p.	melting point	satn.	saturation
		sec.	second(s)
N.	normal	scien.	scientifically, scientific
		sep.	separate
org.	organic	sepd.	separated
operg.	operating	sepg.	separating
opern.	operation	sepn.	separation
oper.	operate	sol.	soluble
p. d.	potential difference	soln.	solution
phys.	physical	soly.	solubility
physiol.	physiological	sp.	specific
Port.	Portland	sp. gr.	specific gravity
powd.	powdered	sq. cm.	square centimeter(s)
prac.	practical	specif.	specifications
ppt.	precipitate	stand.	standard
pptd.	precipitated	subs.	substance
pptg.	precipitating		
pptn.	precipitation	temp.	temperature
press.	pressure	tent.	tentative
prep.	prepare		
prepd.	prepared	v.	volt(s)
prepg.	preparing	vol.	volume (not volatile)
prepn.	preparation	wt.	weight



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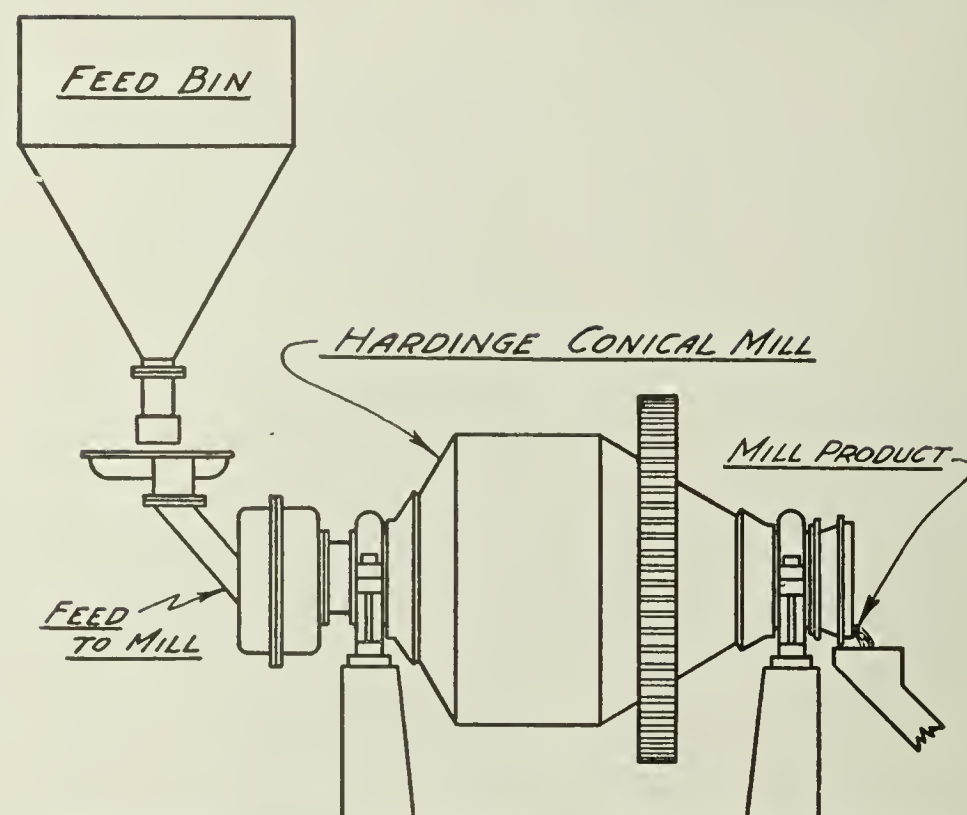
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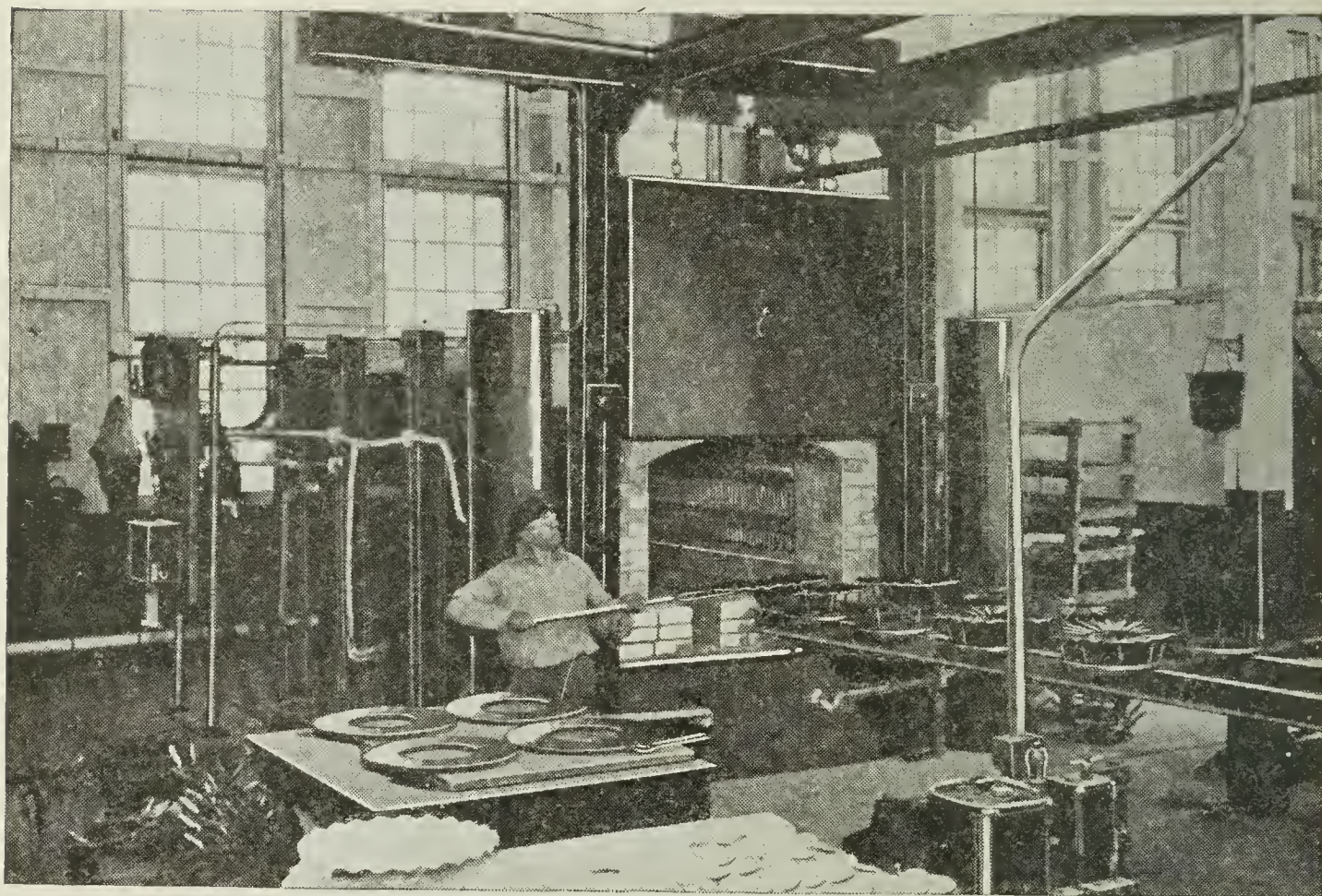
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	PAGE
Bowman Coal Company.....	22
Brown Instrument Co.....	18
Ceramic Engineering Co.....	15
Chambers Brothers Co.....	22
Chicago Vitreous Enamel Product Co., The.....	1
Drakenfeld and Co., B. F., Inc.....	10
Edgar Brothers Co.....	22
Engelhard, Charles, Inc.....	15
Ferro Enamel Supply Co.....	16
Gay, Rubert M. Co.....	25
General Electric Co.....	12
Golding-Keene Co.	16
Hadfield-Penfield Steel Co.....	17
Hardinge Co., Inc.....	8
Harshaw, Fuller and Goodwin Co.....	2
Journal of the Society of Glass Technology.....	20
Lindsay Light Co.....	15
Madeira Hill & Company.....	19
McDanel Refractory Porcelain Co.....	16
Metal & Thermit Corporation.....	21
Montgomery Porcelain Products Co.....	17
Mueller Machine Co.....	23
O'Brien and Fowler.....	16
Paper Makers Importing Co., (Inc.).....	26
Parker-Russell Mining & Mfg. Co.....	14
Pennsylvania Pulverizing Co.....	19
Philadelphia Drying Machinery Co.....	18
Porcelain Enamel & Mfg. Co.	Inside Back Cover
Proctor and Schwartz, Inc.....	6
Roessler and Hasslacher Chemical Co.	Inside Front Cover
Seaboard Fuel Corporation.....	24
Surface Combustion Co.....	14
United Alloy Steel Co.,.....	17
United Clay Mines Corp.....	17
U. S. Smelting Furnace Co.....	5
Vanderbilt Co., R. T.....	4
Vitro Manufacturing Co.....	Outside Back Cover
Wilson-Maeulen Co., Inc.....	16

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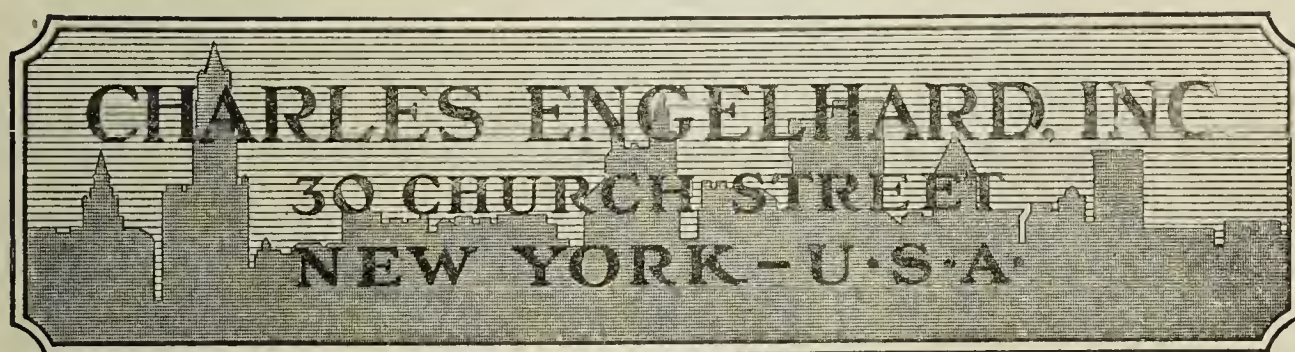
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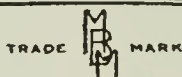
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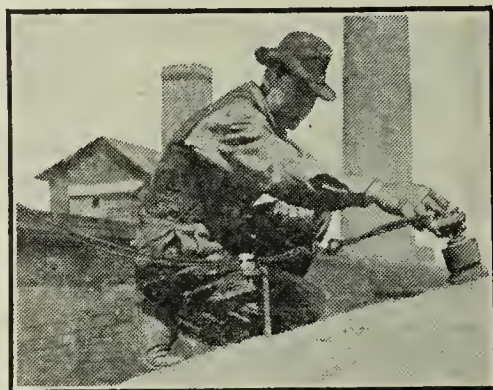
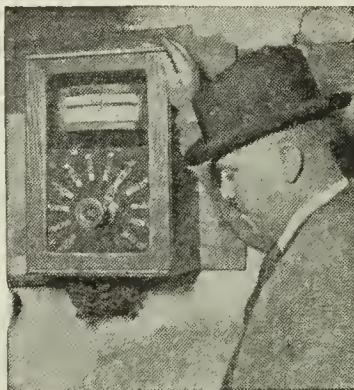
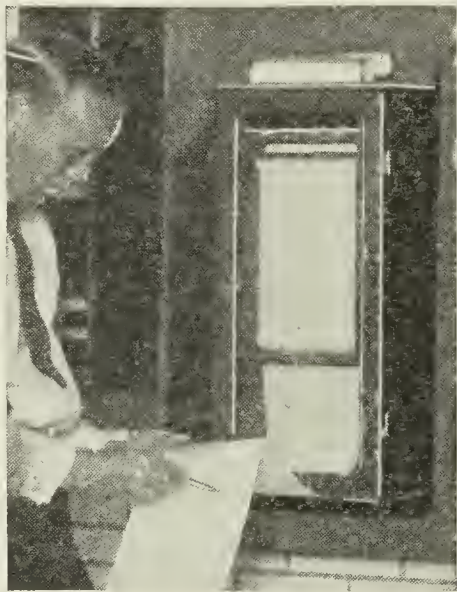
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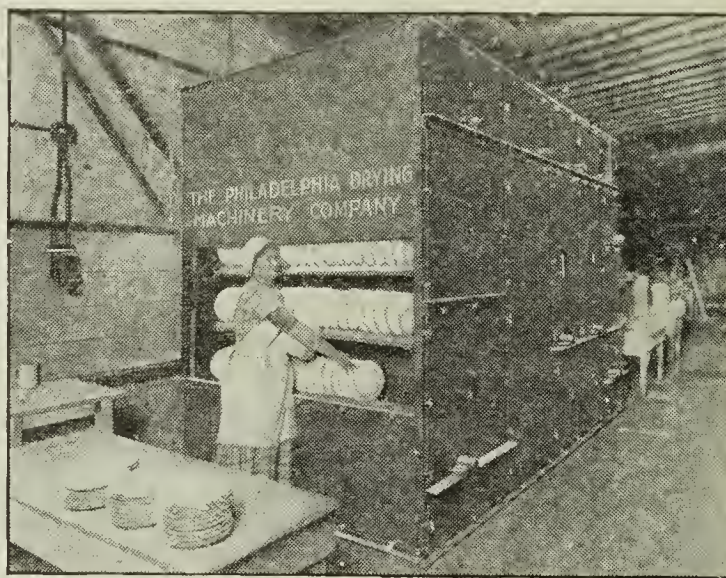
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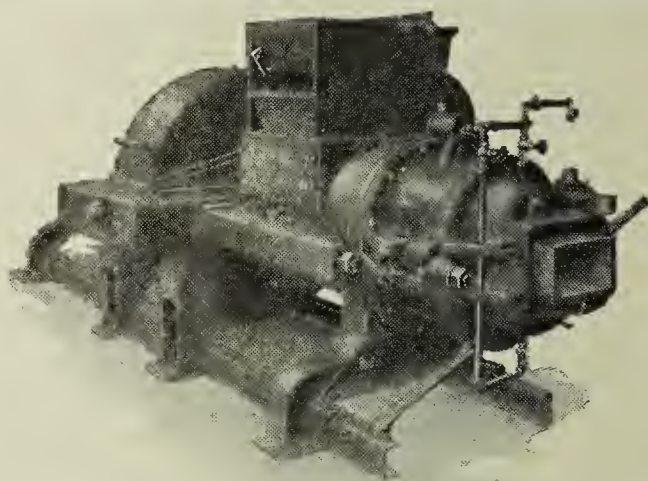
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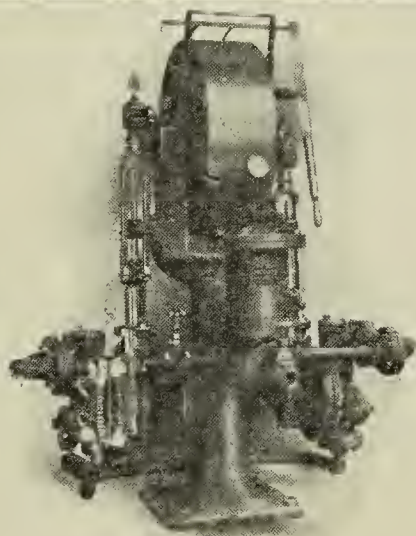
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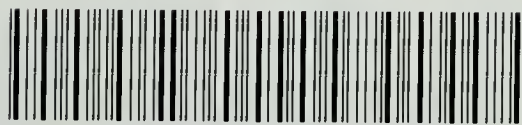
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